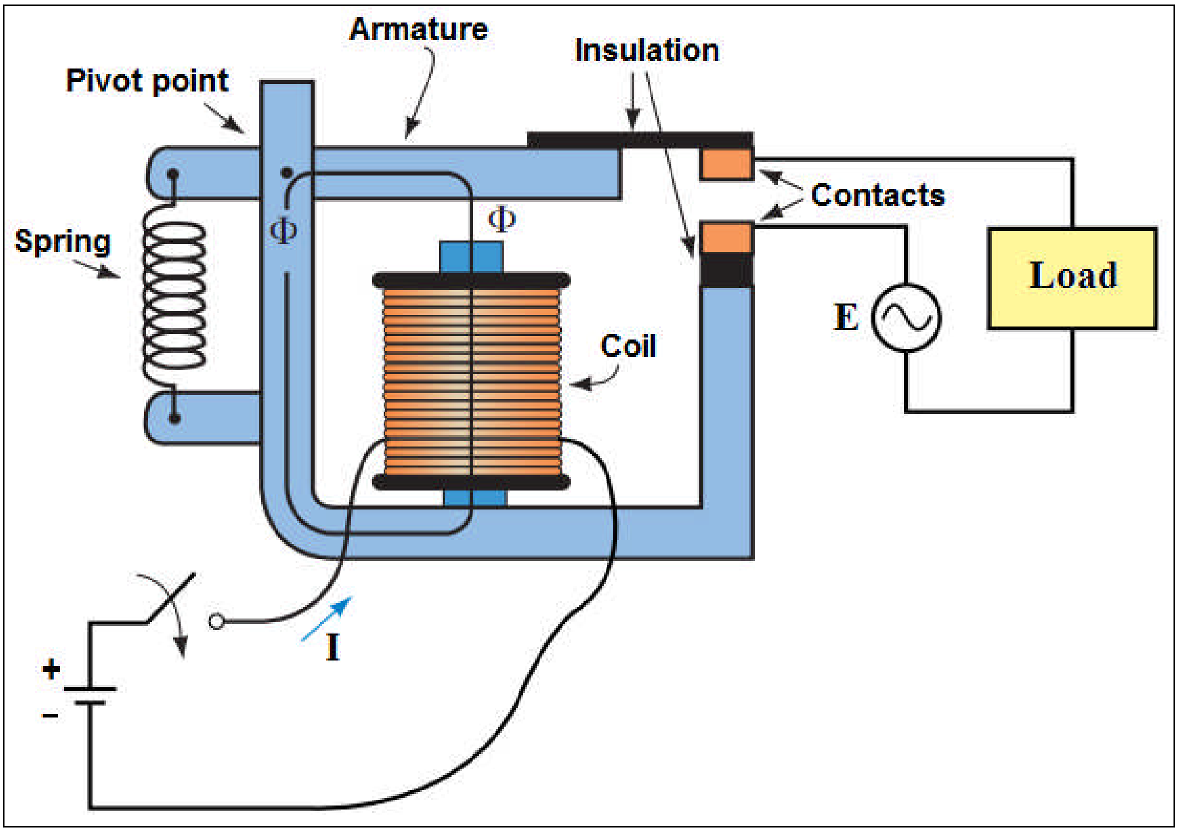


POWER SYSTEM PROTECTION AND CONTROL

STAGE 1-B

TEXTBOOK/WORKBOOK 1 of 2

INDUSTRIAL TRAINING PROGRAM (ITP)

(ELECTRICAL)

POWER SYSTEM PROTECTION AND CONTROL

STAGE 1-B

Textbook/Workbook 1 Of 2

TABLE OF CONTENTS

POWER SYSTEM PROTECTION AND CONTROL
STAGE 1-B
TEXTBOOK/WORKBOOK

COURSE OVERVIEW

OVERVIEW

Power system protection and control stage (1-B) introduces theoretical concepts and workshop practices required to develop knowledge and hand skills of trainees for safe use of electrical equipment/instruments.

OBJECTIVES

Upon completion of this course, the trainees will be able to:

- Follow safety rules to avoid electrical hazards.
- Apply Ohm's Law applications in series-parallel circuits.
- Use testing & measuring instruments properly.
- Learn properties of magnetism and its AC applications.
- Analyze properties of inductance and capacitance in AC/DC circuits.
- Analyze the single and three phase power circuits.
- Discuss the procedures to correct power factors in a power system.
- Apply knowledge and skills to operate and maintain the AC/DC motors.
- Explain the purpose and applications of the transformer.
- Identify semiconductor applications.
- Identify the different types of transistors.
- Understand the operation of an oscillator.
- Identify electrical power system components and, briefly, explain their functions.

CONTENT

This course is composed of two books. Book 1 of 2 has two (2) units of instruction with ten (10) lessons and Book 2 of 2 has four (4) units of instructions with ten (10) lessons.

TEXTBOOK/WORKBOOK 1 OF 2:

Unit 1: Electrical Fundamentals

Unit 2: AC/DC Circuit Fundamentals

TEXTBOOK/WORKBOOK 2 OF 2:

Unit 3: Motor Control Fundamentals

Unit 4: Transformers

Unit 5: Semiconductor Fundamentals

Unit 6: Power Sources and Sec Network

DURATION

The course is designed for two hundred sixteen (216) hours that is divided into theoretical and practical instruction.

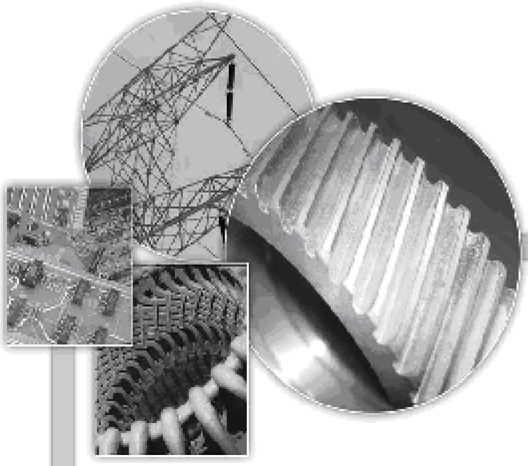
POWER SYSTEM PROTECTION AND CONTROL

STAGE 1-B

TEXTBOOK/WORKBOOK 1 OF 2

PACING SCHEDULE

Unit	Description	Duration (hours)
1	Electrical Fundamentals	45
2	AC/DC Circuit Fundamentals	54
	Review	9
	TOTAL	**108**



UNIT 1

ELECTRICAL FUNDAMENTALS

UNIT-1

ELECTRICAL FUNDAMENTALS

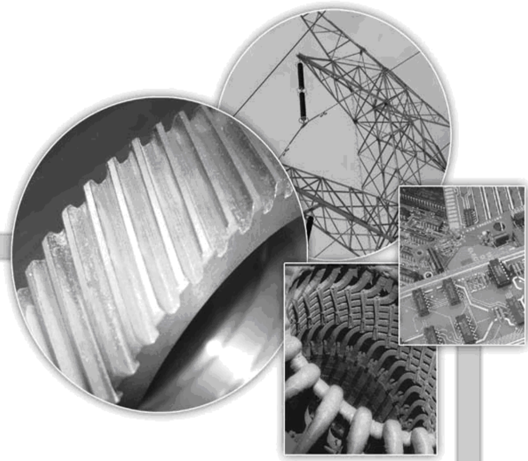
OVERVIEW

In this unit for electrical fundamentals, the trainees will learn electrical safety, ohm's law, electrical measurements, oscilloscope fundamentals, magnetism and its applications.

OBJECTIVES

Upon completion of this unit, the trainees will be able to:

- Follow safety rules to avoid electrical hazards.
- Apply Ohm's Law applications in series-parallel circuits.
- Use electrical instruments for AC measurements.
- Learn properties of magnetism and its AC applications.



LESSON 1.1

ELECTRICALSAFETY

LESSON 1.1
ELECTRICAL SAFETY

OVERVIEW

This lesson introduces electrical hazzards and safety precautions, discusses electrical shock, electrical burns, electrical fires, injury from misuse of electrical tools and equipment. Also it will introduce worshop safety, personal safety, plant and equipment safety.

OBJECTIVES

Upon completion of this lesson the trainees will be able to:

- Identify and avoid electrical hazards.
- Apply safety rules and precautions while working on live electric circuits.
- Identify and avoid electrical hazards in workshop and plant equipment and practice proper personal safety as required.

INTRODUCTION

Safety is everyone's responsibility. Everyone must cooperate to create the safest possible working conditions. Where the personal life and good health are concerned, safety becomes the responsibility of each concerned person.

It is possible for you to complete a full career without a serious accident or injury. To do this, you must be aware of the main sources of danger and keep alert to those dangers. You must take proper precautions and practice basic safety rules at all times.

In most of **Relay Technician** work on electrical circuits and devices, he will work with low voltage and low current. Voltage will usually' be less than 220 volts AC, 220 volts DC. Current will usually be less than 5 Amperes.

The single most important electrical safety rule, you can follow, is:

IF YOU DON'T KNOW THE VOLTAGE LEVEL, DON'T TOUCH IT.

When working with high voltage, a rubber mat should be used to isolate you from all conductors other than the circuit that you are working on, thus, preventing you from becoming grounded. This will prevent current passing through the body if you accidentally touch an electrical "**Hot Spot**" in the equipment. You should remove all jewelry before starting work on a hot (turned **ON**) circuit. Most rings is made of conductive metals and therefore conducts current easily.

Gold and silver are two of the very best current conductors and could easily draw an arc from a high voltage source. There are many documented cases of a gold wedding band ring is melting while it still attached to a finger. It is therefore recommended that you work with only one hand. This will ensure that if you are shocked you won’t be grounded and current will not flow one hand through the body and out the other hand. It is possible for a very small amount of current to cause death.

FACTS ABOUT HAZARDS OF WORKING; WITH ELECTRICAL AND ELECTRONICS EQUIPMENT:

ELECTRICAL BURNS

Electrical burns can occur if the body contacts an electrical circuit or is struck by lightning.

ELECTRICAL FIRES

Electrical fires can occur if electrical wires become heated because of an overloaded circuit and contact flammable materials.

INJURY FROM MISUSE OF TOOLS

Body injuries can be caused by the improper use of tools.

ELECTRIC SHOCK

Electric shock occurs when a person becomes part of the electrical circuit (Fig. 1.1-1). Not everyone would have the same level of shock from the same source. The intensity of shock will depend on a current resulting from voltage source (normally constant) and human body resistance, the resistance varying from about 500,000 Ohms when dry to about 300 Ohms when wet. Voltages as low as 30 volts can cause enough current to be deadly due to low resistance in the circuit. Any circuit with a potential of at least 30 volts must be considered dangerous.

However, it is generally accepted that 50mA (0.05A) at 230V can be dangerous. Below this level, contact with a live source throws us away from the source. Above 50 mA the muscles contract or freeze and we are unable to break contact.

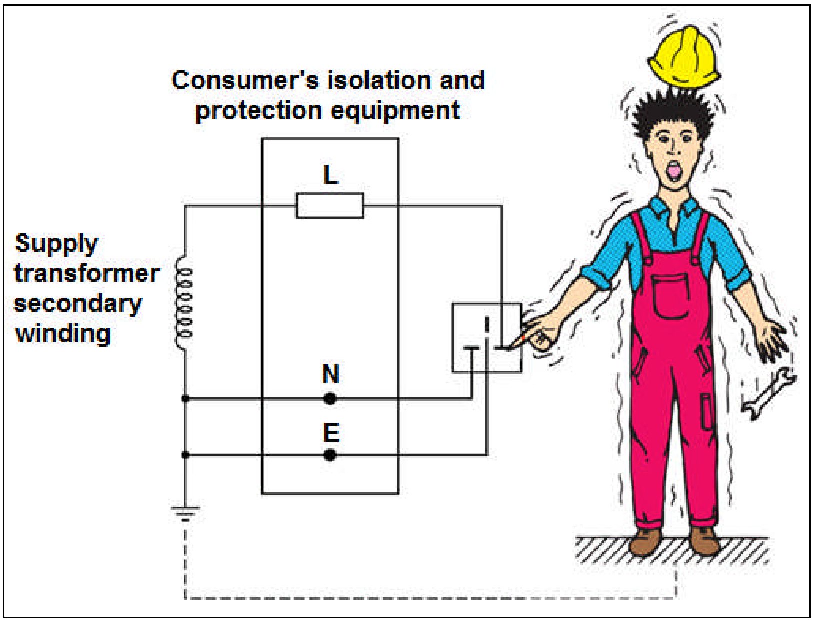


Fig. 1.1-1 Touch Electrical Equipment

Actions to be taken upon finding a workmate receiving an electric shock are as follows:

1. Do not touch the injured person with the hands.
2. Switch off the supply.
3. If this is not possible, pull the injured person away from contact using insulating material.
4. If heart or breathing or both have stopped, apply cardiac massage until the injured person recovers.
5. Treat for burns.
6. Check for other injuries; treat as necessary.
7. Treat for shock.
8. Call for medical assistance.

SAFETY EQUIPMENT

The following safety equipment (Fig. 1.1-2) is designed to protect craftsmen while performing the assigned duties under hazardous conditions.

Fig. 1.1-2 Safety Equipment

WORKSHOP SAFETY

It is necessary that everybody in the workshop should apply precisely the workshop safety rules as stated in SEC manuals. Any loss of misapplying safety rules may lead to self-and/others injury, which in turn is a lost productive time.

The following rules will help you remind rules. For more rules, refer to **SEC- Safety Manual**:

- Wear safety shoes and dress in workshop.
- Use safety glasses and face shield when specific job requires that.
- Use each tool for the job, only it is designed for.
- Tools must be clean, free of rust with edges and ends not broken.
- Tools on use must be free of grease.

- Store tools properly after use.
- Electric current being too dangerous, handle it carefully.
- Make sure you are using the proper power supply before switching on.
- Dry immediately any spoiled liquid.
- Mercury being poisonous, do not touch or smell its vapor.
- No eating, drinking or smoking in the workshop.
- Keep the workshop always clean.

PERSONAL AND EQUIPMENT SAFETY HAZARDS

The following section presents some common hazards involved in electrical instrument work. Each hazard is explained in the Information Sheet. Necessary precautions are listed for each hazard. Be aware of these hazards and observe the precautions while working hazardous areas.

WEARING RINGS, WATCHES, BRACELETS AND OTHER METAL OBJECTS WHILE WORKING ON LIVE ELECTRICAL CIRCUITS

Metal objects are conductors. Metal objects make a good path for electricity to flow. If you are wearing metal objects on the hands and these objects touch an electric circuit, two things can happen to you:

1. You can receive an electric shock.
2. You can be hardly burned because the electricity will follow a circular path around the ring, watch band, bracelet or chain.

Remove rings, watches, before working on electrical circuits. Put them in the pocket**.**

USING METAL TOOLS

Metal tools are **conductors**. If you touch a live electric circuit with a tool that is not insulated, the electricity will travel through the tool into the body. Use tools that have insulated handles like the ones in Fig. 1.1-3.

Fig. 1.1-3 Insulated Handles Tools

WORKING ON LIVE EQUIPMENT IF YOU HAVE A WET CLOTHING, HANDS OR FEET

Water is a very good conductor of electricity. A wet shirt sleeve that is close enough to a live electric wire or device can have the same effect as putting the hand on the wire, which will cause an electric shock.

Keep the hands dry. Wear dry clothes and shoes. Remember that wet gloves do not protect you from electric shock.

DOING AN ELECTRICAL WORK IN A HURRY

Trying to do a job in a hurry; leads to carelessness. Carelessness can lead to serious trouble when you work with electricity. Always take extra few minutes to de-energize the electrical circuit or device you are working on.

Take the time when you work with electricity. Think about what you are doing.

TOUCHING ENERGIZED ELECTRICAL DEVICES WITH BOTH HANDS

When you touch electrical equipment, wire terminals and power sources, you can make yourself part of an electric circuit.

Work on live electric equipment and circuits with **one hand only**. Of course, the best bet is to **de-energize the equipment or circuit** if you **do not need** current flow.

WORKING AT UNSAFE WORK AREA

Any work area that is filled with trash, junk, rags and objects you can slip over will make the work area unsafe. In addition to the fire hazard, you can hurt yourself, have objects fall on you and you can slip and fall yourself.

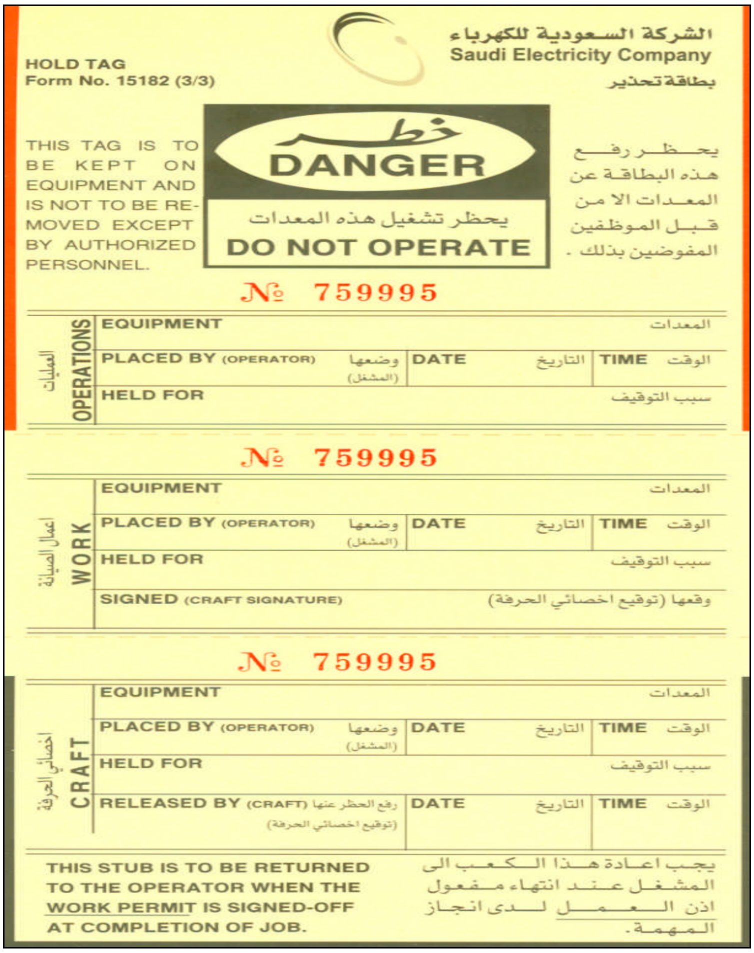
Always look where you are going. Look behind you before you move backward. Move objects you might slip over.

IGNORING HOLD TAGS

Hold Tags (Fig. 1.1-4) are placed on equipment and switches to keep you or someone else from being hurt or some piece of equipment from being damaged.

Look for and obey Hold Tags. When Hold Tags are placed on equipment it means **do not operate this**

If you want other workers to obey the Hold Tags you may have placed on equipment, you must obey the Hold Tags others have placed.



HOLD TAG
Form No. 15182 (3/3)

الشركة السعودية للكهرباء
Saudi Electricity Company
بطاقة تحذير

THIS TAG IS TO BE KEPT ON EQUIPMENT AND IS NOT TO BE REMOVED EXCEPT BY AUTHORIZED PERSONNEL.

خطر
DANGER
يحظر تشغيل هذه المعدات
DO NOT OPERATE

يحظر رفع هذه البطاقة عن المعدات الا من قبل الموظفين المفوضين بذلك .

№ 759995

OPERATIONS العمليات
EQUIPMENT المعدات
PLACED BY (OPERATOR) وضعها (المشغل) | DATE التاريخ | TIME الوقت
HELD FOR سبب التوقيف

№ 759995

WORK أعمال الصيانة
EQUIPMENT المعدات
PLACED BY (OPERATOR) وضعها (المشغل) | DATE التاريخ | TIME الوقت
HELD FOR سبب التوقيف
SIGNED (CRAFT SIGNATURE) وقعها (توقيع اخصائي الحرفة)

№ 759995

CRAFT اخصائي الحرفة
EQUIPMENT المعدات
PLACED BY (OPERATOR) وضعها (المشغل) | DATE التاريخ | TIME الوقت
HELD FOR سبب التوقيف
RELEASED BY (CRAFT) رفع الحظر عنها (توقيع اخصائي الحرفة) | DATE التاريخ | TIME الوقت

THIS STUB IS TO BE RETURNED TO THE OPERATOR WHEN THE WORK PERMIT IS SIGNED-OFF AT COMPLETION OF JOB.

يجب اعادة هذا الكعب الى المشغل عند انتهاء مفعول اذن العمل لدى انجاز المهمة .

Fig. 1.1-4 Hold Tag (Form 15182)

INSTALLING WRONG FUSE

Remember that a fuse is put into an electrical circuit to protect equipment from too much current. Just because a fuse burns out, it does not mean the circuit is dead. If you touch both ends of the fuse holder, you become the fuse. Always, turn off the power supply to the circuit before you try to change a fuse.

Whenever a fuse is replaced, it must be replaced by the same kind of fuse. The voltage rating and the current rating must be checked carefully to make sure the new fuse is the same as the old one.

Replace a burnt out fuse with a new one that should have the same voltage and current rating.

MODIFYING ELECTRICAL EQUIPMENT WITHOUT AUTHORITY

Modifying electrical equipment or changing the way a piece of equipment is made without authority is a dangerous practice. Electrical equipment is designed and built to operate a certain way. Safety features and devices are built-in. When you modify the electrical equipment, you may create a dangerous piece of equipment.

USING DAMAGED MULTIMETER

The electrical device you will use most often is a multimeter. A damaged multimeter can be dangerous device in two ways:

1. If the meter is damaged it may give an incorrect reading. You may think the circuit is dead while it is alive. You could receive an electrical shock.
2. If the insulation of the test probes and leads are damaged you could again receive an electrical shock.

Always inspect electrical multimeter. If it is damaged, don't use it.

PRECAUTIONS WHEN WORKING WITH ELECTRICITY

1. Never work on live equipment (unless a special live test is required, for which you will need to be an experienced and qualified person).
2. Always ensure, by using approved test instruments, that equipment is dead.
3. Never accept another person's word that a circuit is safe to work on; always check.
4. Ensure that all supplies to equipment to be worked on are isolated at the suitable places and locked '**OFF**' if possible, and that all supply fuses are removed and keep in a safe place.
5. If work is to be performed on dead equipment which is adjacent to live supplies, ensure that barriers are used to define safe areas, or '**DANGER LIVE APPARATUS**' notices are placed on all adjacent live equipment.

PROPER OPERATING PROCEDURE WHEN USING POWER SUPPLY IN RELAY WORK SHOP

The power sources, when properly handled, will provide years of reliable service and will prevent any danger to the user.

I GENERAL DESCRIPTION OF POWER SOURCES

a. Most power supplies have **ON-OFF** switches. A panel lamp is generally provided to show when they are **ON**.

b. All variable power supplies have some type of control for varying the output voltage. Most of them use a variable control, which permits setting any desired voltage within the range of the supply. There are some, however, that have switches for selecting a number of set voltage levels.

C The power circuits are usually protected against overloads by fuses, circuit breakers, current limiters or similar devices.

d. Power is generally available from two or more terminals. They may be binding posts; banana jacks or power receptacles.

e. Power sources used in industrial workshops and laboratories should have their enclosures and panels connected to electrical earth ground by means of a three-wire input system or a separate ground lead.

II. PROPER OPERATION OF POWER SOURCES

a. Before turning the power supply on, carefully inspect the test setup. Make sure the power supply and meter leads are connected with the correct polarity.

b. Make certain all variable voltage controls are set for minimum voltage before applying power.

c. After the power supply is turned on, slowly advance the variable voltage control to the desired voltage.

d. If the output voltage does not change as the voltage control is advanced, check the circuit breaker, it might be open. The ON-OFF lamp shows only that power is applied to the input of the power supply; but it does not indicate the presence of voltage at the output terminals.
e. Before resetting the circuit breaker, return the voltage control to the minimum setting and correct any cause of overload. Then press and release the reset button.
f. If, instead of a circuit breaker, the output terminals are protected by a fuse, check with the instructor before replacing the fuse.

SAFE USE OF ELECTRICAL EQUIPMENT

When one is using electrical equipment such as drills, saws, sanders, etc., on site or in a workshop, great care must be taken to ensure that the tools are in good condition and that the cables supplying them are not damaged in any way and are adequate for the job they have to do.

Any connections of cables must be carried out by a qualified person using approved tools and equipment.

All current-using and current-carrying apparatus used on sites must be inspected and checked at regular intervals, but the user should always check before use that all electrical apparatus is in good condition.

Ensure that all cables exposed to mechanical damage are well protected.

SAFETY SIGNS

The rules and regulations of the working environment are communicated to employees by written instructions, signs and symbols (Fig. 1.1-5). All signs in the working environment are intended to inform. They should give warning of possible dangers and must be obeyed.

Fig. 1.1-5 Prohibition Safety Signs

SUMMARY

- Safety is everyone's responsibility.
- Everyone must cooperate to create the safest possible working conditions.
- In most of Relay Technician work on electrical circuits and devices, he will work with low voltage and low current.

- When working with high voltage, a rubber mat should be used to isolate you from all conductors other than the circuit that you are working on.
- Gold and silver are two of the very best current conductors and could easily draw an arc from a high voltage source.
- Electric shock occurs when a person becomes part of the electrical circuit.
- Electrical burns can occur if the body contacts an electrical circuit or is struck by lightning.
- Body injuries can be caused by the improper use of tools.
- Not everyone would have the same level of shock from the same source.
- The human resistance varying from about 500,000 Ohms when dry to about 300 Ohms when wet.
- Voltage as low as 30 volts can cause enough current to be deadly.
- When you touch electrical equipment, wire terminals and power sources, you can make yourself part of an electric circuit.
- Modifying electrical equipment or changing the way a piece of equipment is made without authority is a dangerous practice.
- Remove rings, watches, before working on electrical circuits.
- Work on live electric equipment and circuits with one hand only.
- Hold Tags are placed on equipment and switches to keep you or someone else from being hurt or some piece of equipment from being damaged.
- Replace a burnt out fuse with a new one that should have the same voltage and current rating.
- Always inspect electrical multimeter. If it is damaged, don't use it.
- The rules and regulations of the working environment are communicated to employees by written instructions, signs and symbols.

GLOSSARY

Safety	The state of being free from danger, personal risk or injury
Accident	Any unplanned event, occurring suddenly, which causes personal injury or damage to property
Conductive material	Materials through which electrical current flows easily
Electrical shock	When electrical current passes through a part of the body
Insulating material	Materials through which electrical current cannot flow easily
Overloaded circuit	An electrical circuit, which is drawing more electrical current than it is designed to handle
Fuse	A device, which opens the circuit "burns out" when the circuit is overloaded
Circuit breaker	A device, which automatically opens the circuit like a switch, if too much current is being drawn by the overload or short circuit
Workmate	Colleague or a person who is member of your class or profession
Cardiac	Belong to heart
Trash	Waste material
Junk	Material which has been thrown out
Rags	Old scraps
Poisonous	Deadly

REVIEW EXERCISE

1. List four (4) precautions when working with electricity:
   a. ________________________________
   b. ________________________________
   c. ________________________________
   d. ________________________________

2. Check True for the correct sentence and False for the wrong sentence:

	T	F
a. - It is not dangerous for the technician to wear all jewelry before starting work on a hot (turned on) circuit.		
b. - Do not use metal ladders or un-insulated metal tools on or near circuits.		
c. - It is not hazardous to work on Live Equipment if you have a wet clothing or wet hands or wet feet.		
d. - When hold tags are placed on equipment, it means you can operate this piece of equipment.		
e. - Human body resistance is about 500,000 Ohms when wet.		
f. - Safety is only the responsibility of a Group Leader.		

Choose the correct answer:

3 Human body resistance varies from about ________ when dry to about _______ when wet.

a.- 500KΩ, 300Ω — b.- 300 K Ω, 500Ω

c.- 200 KΩ, 600Ω — d.-100 KΩ, 400Ω

4. If a Technician touches live electric circuit with a tool that is not insulated, the electricity will travel through the ____________ into his body

a.- insulator — b.- Helmet

c.- tool — d.- Shoes

5. If a technician works on a Live Electric Circuit with carelessness, ______________.

   a.- his supervisor will be happy b.- it can lead to serious trouble

   c.- he will complete the job fast d.- the circuit voltage will decrease

6. Before using any item of test equipment for the first time, the Technician should ask for __________, even if he thinks that he knows it.

   a.- its price b.- its size

   c.- its weight d.- its instruction manual

Complete by filling in blanks:

7. The _______ rating and the ______ rating of a new Fuse must be checked carefully to make sure that it is the same as the old one.
8. When working with high voltage, ___________ should be used to isolate the Technician from all conductors other than the circuit that he is working on.
9. Electrical fires can occur if electrical wires become heated because of _______ circuit and contact flammable materials.
10. Electrical shock can occur if the ________ contacts an electrical circuit or is struck by lightning.
11. What is the minimum voltage, which can cause enough current to be fatal for a humane if touch it? ______________
12. List six (6) of workshop SEC standard safety rules:

    ____

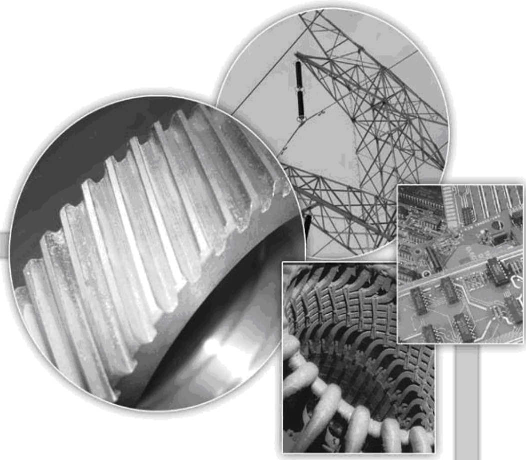
    ____

    ____

    ____

    ____

    ____



LESSON 1.2

OHM’SLAW APPLICATIONS

LESSON 1.2

OHM'S LAW APPLICATIONS

OVERVEIW

This lesson will demonstrate ohm's laws and how they can be used for solving equations in electrical networks.

OBJECTIVES

Upon completion of this lesson, the trainees will be able to:

- State Ohm's laws.
- Explain the difference between power and energy.
- List electrical power precautions.
- Explain function of ground as a voltage reference.
- State Kirchhoff's laws.

Task 1.2-1: Ohm’s Law

Task 1.2-2: Ohm’s Law Applications

OHM'S LAW

The current (Amperes) in an electric circuit equals the electromotive force or potential (volts) divided by the resistance (Ohms), as shown in Fig. 1.2-1.

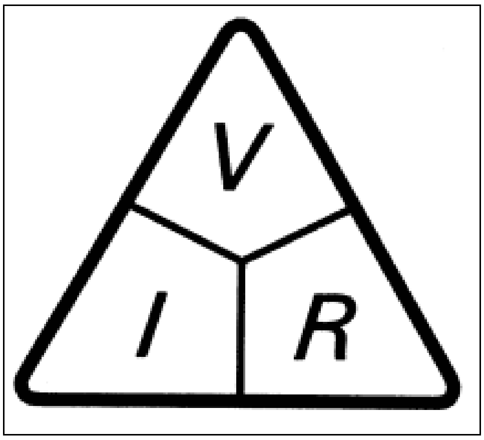


Fig. 1.2-1 Triangle Showing Relationship between V, I and R

The formula may be arranged to make V, I and R the subject, as follows:

V = I x R **I = V/R** **and** **R=V/I**

Where:

V = electromotive force or potential (volts)

I = Electrical current (Amperes)

R = Resistance (Ohms)

EXAMPLE 1.2-1

A 12 resistor is connected to a 6 V battery. What current will flow in the resistor?

SOLUTION

Here we must use I = V/R (where V = 6 V and R= 12 Ω):

I = V/R = 6V/12 Ω = 0.5A (or 500mA)

Hence a current of 500 mA will flow in the resistor.

POWER AND ENERGY

At first you may be a little confused about the difference between energy and power. Energy is the ability to do work while power is the rate at which work is done. In electrical circuits, energy is supplied by batteries or generators. It may also be stored in components such as capacitors and inductors. Electrical energy is converted into various other forms of energy by components such as resistors (producing heat), loudspeakers (producing sound energy) and light emitting diodes (producing light).

The unit of energy is the **Joule** (**J**). Power is the rate of use of energy and it is measured in **Watts** (**W**). A power of **1 W** results from energy being used at the rate of **1 J** per **second**. Thus:

P = E/t

Where: **P** = Power (**W)** **E** = Energy (**J)** **t** = time (**seconds**)

The power in a circuit is equivalent to the product of voltage and current (Fig. 1.2-2).

P = I x V

Where: **P=** Power (**W**) **I =** Current (**A**) **V =** Voltage (**V**)

The formula may be arranged to make **P, I or V** the subject, as follows:

P = I x V **I = P/V** **and** **V = P/l**

The triangle (Fig. 1.2-2) should help you remember these relationships.

The relationship, **P = I x V**, may be combined with that which results from Ohm's law **(V = I x R)** to produce two further relationships. First, substituting for **V** gives:

P = I x (I x R) = I^2R

Secondly, substituting for **I** gives:

P = (V/R) x V = V^2/R

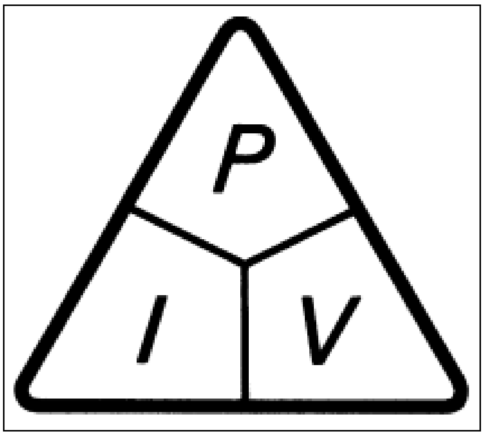
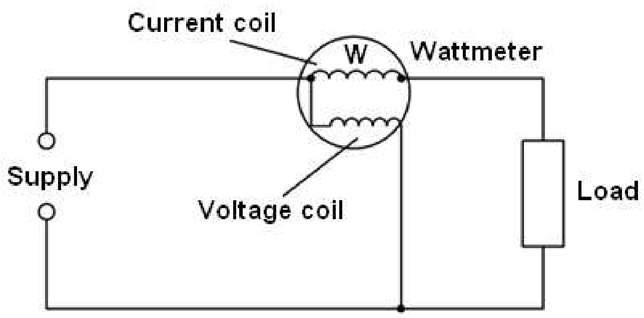
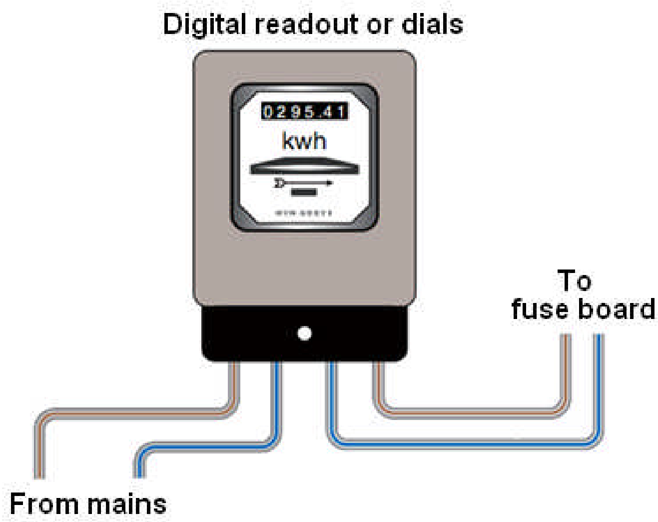


Fig. 1.2-2 Triangle Showing Relationship between P, I and V

MEASURING POWER AND ENERGY

A wattmeter is connected (Fig. 1.2-3). It is basically a combination of an ammeter and a voltmeter, and it measures the product of current and voltage: **P** (watts) = **I x V**	 Fig. 1.2-3 Wattmeter Connections

An energy meter (Fig. 1.2-4) is similar to a wattmeter and its connections are the same. However, it is designed to show the number of kilowatt hours of energy used. It is familiar to most of us as our electricity meter.	 Fig. 1.2-4 Energy Meter

EXAMPLE 1.2-2

A domestic consumer has the following daily loads connected to the supply:
Five 60 W lights for 4h, two 3 kW electric fires for 2h, one 3 kW water heater for 3 h, one 2 KW kettle for 0.5 h. Calculate the energy consumed in 1 month.

SOLUTION

Light	E = 5 X 60 X 4= 1200 Wh= 1.2 kWh
Electric fires	E = 2 X 3X 2 = 12.0 kWh
Water heater	E = 1 X 3 x 3= 9.0 kWh
Kettle	E = 1 x 2 x 0.5 = 1.0 kWh
Total for 1 day	= 23.2 kWh

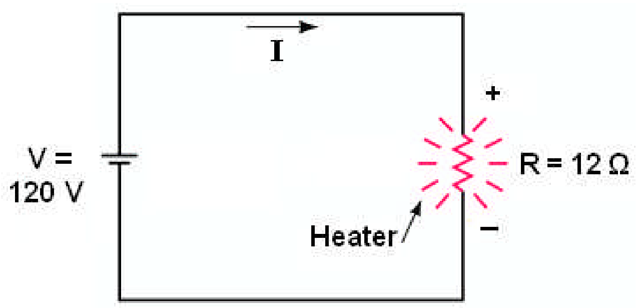
Energy expended in 1 month = 30 x 23.2 = 696 kWh

FORMULAS USED TO COMPUTE ELECTRICAL POWER

a. When current and voltage are known: $\mathbf{P = V \times I}$

b. When current and resistance are known: $\mathbf{P = I^2 \times R}$

c. When voltage and resistance are known: $\mathbf{P = V^2 / R}$

EXAMPLE 1.2-3 Compute the power supplied to the electric heater (Fig. 1.2-5) using all three electrical power formulas.	 Fig. 1.2-5 Example 1.2-3

SOLUTION

$I = V/R = 120\ V/12 = 10\ A.$

Thus, the power may be calculated as follows:

a. $P = V \times I = (120V) \times (10A) = 1200\ W$

b. $P = I^2 \times R = (10\ A)^2 \times (12\ \Omega) = 1200\ W$

c. $P = V^2 / R = (120\ V)^2 / 12\ \Omega = 1200\ W$

NOTE

All give the same answer, as they must.

WATTAGE RATING OF RESISTORS

a. Resistors have Ohm values and wattage ratings.
b. Wattage rating indicates the maximum amount of power that a resistor can handle before it burns up.
c. Use a wattage safety factor of 2 when choosing resistors; the wattage rating should double the expected power level of the circuit.
d. Resistor size generally indicates wattage rating:
   - Small carbon resistors are generally used in circuits, which operate well below 2 watts.
   - Larger wire wound resistors are capable of dissipating the heat generated by higher power levels.

ELECTRICAL POWER SAFETY PRECAUTIONS

Circuit safety precautions

- Never install a fuse or circuit breaker whose current rating is higher or whose voltage rating is lower than specified for a particular circuit.
- Never bypass or defeat a fuse or circuit breaker.

POWER IN PARALLEL CIRCUIT

The total amount of power in a parallel resistive circuit is equal to the sum of the powers in each resistor in parallel. Equation below states this formula in any number of resistors in parallel:

$$\mathbf{P_T = P_1 + P_2 + P_3 + - - - + P_n,}$$

Where $\mathbf{P_T}$ is the total power and $\mathbf{P_n}$ is the power in the last resistor in parallel. As you can see, the power losses are additive, just as in the series circuit.

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EXAMPLE 1.2-4

In Fig. 1.2-6, Calculate:

a. Power consumed by each resistor.

b. Power delivered to the circuit by the voltage source.

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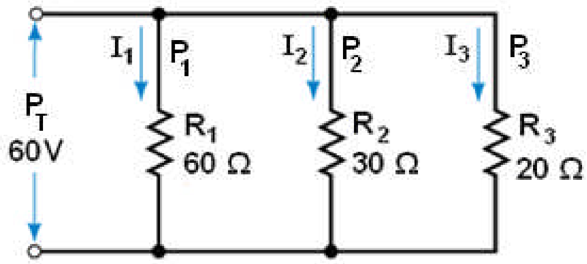

Fig. 1.2-6 Example 1.2-4

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SOLUTION

In Fig. 1.2-6, P_T is taken from the power source, P_1, P_2, P_3, is consumed by R_1, R_2, R_3 resistors.

The resistances are connected in parallel, so the voltage across each is the same. The maximum power to each resistance is:

$$\text{(a)}\ P_1 = \frac{V^2}{R} = \frac{(60\ \text{V})^2}{60\ \Omega} = 60\ \text{W}$$

$$P_2 = \frac{V^2}{R} = \frac{(60\ \text{V})^2}{30\ \Omega} = 120\ \text{W}$$

$$P_3 = \frac{V^2}{R} = \frac{(60\ \text{V})^2}{20\ \Omega} = 180\ \text{W}$$

$$\text{(b)}\ P_T = P_1 + P_2 + P_3$$

$$= 60 + 120 + 180 = 360\ \text{W}$$

VOLTAGE DIVIDER

When two or more resistors are connected in series across a DC supply, different voltages appear across each resistor. Such an arrangement is called a potential divider and it is used to provide different voltages from a single supply voltage.

EXAMPLE 1.2-5

A simple potential divider (Fig. 1.2-7), where R_I =75 Ω, R_2 =25 Ω and supply voltage V = 50 V. Calculate V_1 and V_2?

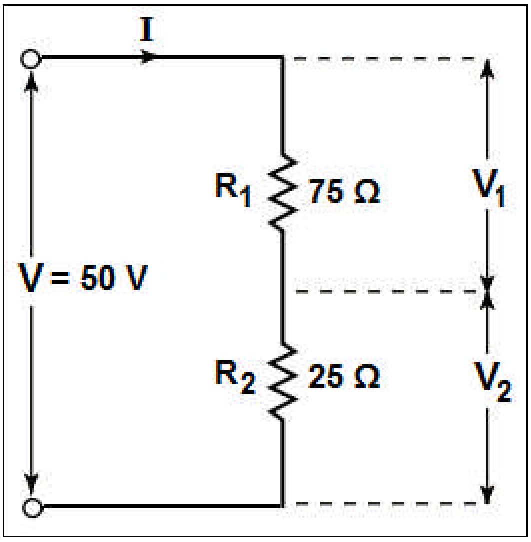


Fig. 1.2-7 Potential Divider

SOLUTION

$$V_1 = \text{Total Voltage} \times \frac{R_1}{\text{Total Resistance}} = 50\,V \times \frac{75\,\Omega}{75\,\Omega + 25\,\Omega}$$

$$= 50\,V \times \frac{75\Omega}{100\Omega} = 37.5\,V$$

$$V_2 = \text{Total Voltage} \times \frac{R_2}{\text{Total Resistance}} = 50\,V \times \frac{25\Omega}{75\Omega + 25\Omega}$$

$$= 50\,V \times \frac{25\Omega}{100\Omega} = 12.5\,V$$

POTENTIAL DIFFERENCE

The potential difference between any two points in a circuit is the difference in their respective voltages. Therefore, the potential difference between A and B in Fig. 1.2-8 is

$$\mathbf{V_{AB} = (V_A - V_B)}$$

Where V_A is the voltage at point A and V_B is the voltage at point B. Both V_A and V_B are measured with respect to the zero line E. The voltage at any point in an electric circuit is always measured with respect to the zero line, chassis or earth.

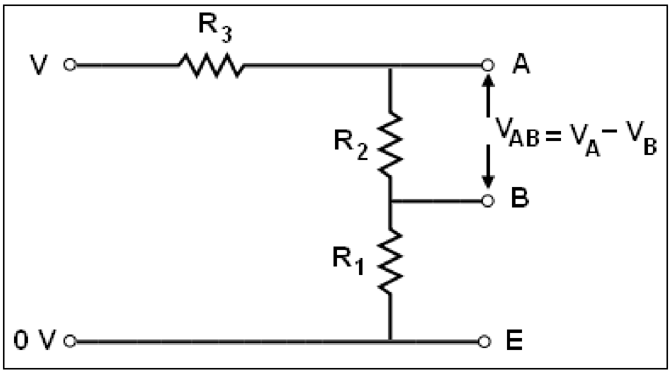
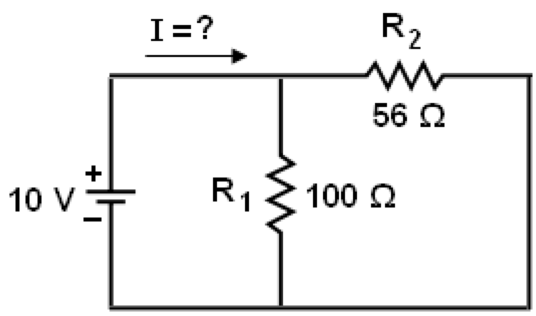


Fig. 1.2-8 Potential Difference

For example, if V_A is 5 V and V_B is 3 V,
$V_{AB} = V_A - V_B = 5 - 3 = 2$ V

EXAMPLE 1.2-6 Find the total current produced by the battery in Fig. 1.2-9.	 Fig. 1.2-9 Example 1.2-6

SOLUTION

STEP 1

The battery "sees" a total parallel resistance, which determines the amount of current that it generates. First, calculate R_T:

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{R_1 + R_2}{R_1 R_2}$$

$$R_T = \frac{R_1 R_2}{R_1 + R_2} = \frac{100\,\Omega \times 56\,\Omega}{100\,\Omega + 56\,\Omega} = \frac{5600\,\Omega}{156\,\Omega} = 35.9\,\Omega$$

STEP 2

The battery voltage is 10 V. Use ohm's law to find I_T.:

$$I_T = \frac{V}{R_T} = \frac{10V}{35.9\,\Omega} = 0.278\ A$$

FUNCTION OF GROUND AS A VOLTAGE REFERENCE

In its most simple definition, **ground** is simply "electrical point of reference" or "common point" (normally zero voltage) in a circuit. Using the ground symbol in this manner usually allows the circuit to be sketched more simply.

The standard symbol for circuit ground is shown in Fig. 1.2-10(a). While the symbol for chassis ground in Fig. 1.2-10(b).

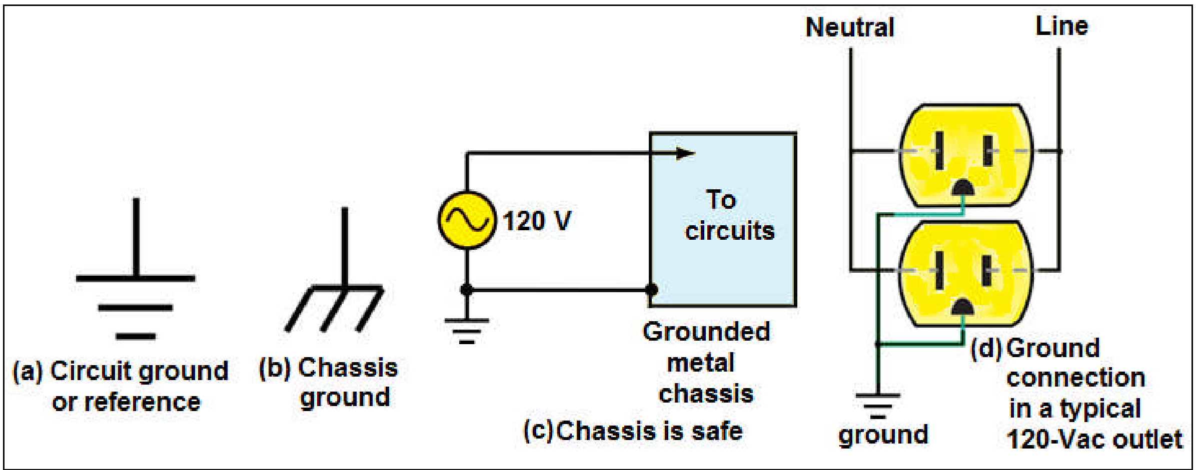
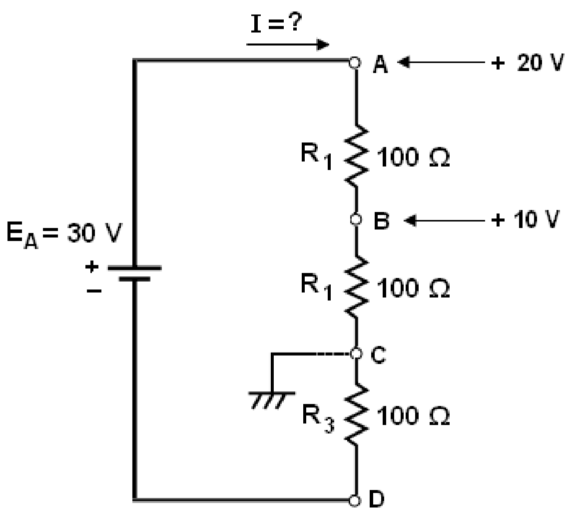


Fig. 1.2-10 Standard Symbol for Circuit Ground

In order to help prevent electrocution, the **chassis ground** is usually further connected to the **earth ground** through a connection, as shown in Fig. 1.2-10(c). In the event of a failure within the circuit, the chassis would redirect current to ground (tripping a breaker or fuse).

As the name implies, the earth ground is a connection, which is bonded to the earth, either through water pipes or by a connection to ground rods. Everyone is familiar with the typical **120-V AC** electrical outlet, Fig. 1.2-10(d).

In the Fig. 1.2-11, the chassis is grounded at point C, which permits positive voltages to be obtained at points A & B and a negative voltage to be obtained at point D.	 Fig. 1.2-11 Example 2-8

KIRCHHOFF'S VOLTAGE LAW

The summation of voltage rises and voltage drops around a closed loop is equal to zero. Symbolically, this may be stated as follows:

$\sum V = 0$ **for closed loop**

An alternate way of stating Kirchhoff's voltage law is as follows: The summation of voltage rises is equal to the summation of voltage drops around a closed loop.

$\sum E_{rises} = \sum V_{drops}$ **for closed loop**

A **closed loop** is defined as any path, which originates at a point, travels around a circuit, and returns to the original point without retracing any segments.

If we consider the circuit of Fig. 1.2-12, we may begin at point **a** in the lower left-hand corner. By arbitrarily following the direction of the current, **I**, we move through the voltage source, which represents a rise in potential from point **a** to point **b**. Next, in moving from point **b** to point **c**, we pass through resistor $\mathbf{R_1}$, which presents a potential drop of $\mathbf{V_1}$ Continuing through resistors $\mathbf{R_2}$ and $\mathbf{R_3}$, we have additional drops of $\mathbf{V_2}$ and $\mathbf{V_3}$ respectively. By applying Kirchhoff's voltage law- around the closed loop, we arrive at the following mathematical statement for the given circuit:

$$\mathbf{E - V_1 - V_2 - V_3 = 0}$$

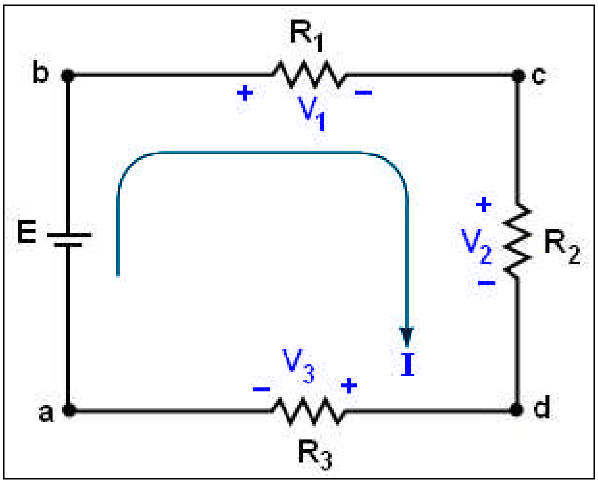


Fig. 1.2-12 Kirchhoff's Voltage Law

Although we chose to follow the direction of current in writing Kirchhoff's voltage law equation, it would be just as correct to move around the circuit in the opposite direction. In this case the equation would appear as follows:

$$\mathbf{V_3 + V_2 + V_1 - E = 0}$$

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EXAMPLE 1.2-7

Verify Kirchhoff s voltage law for the circuit of Fig. 1.2-13.

SOLUTION

If we follow the direction of the current, we write the loop equation as

15V - 2V - 3V - 6V - 3V - 1 V = 0

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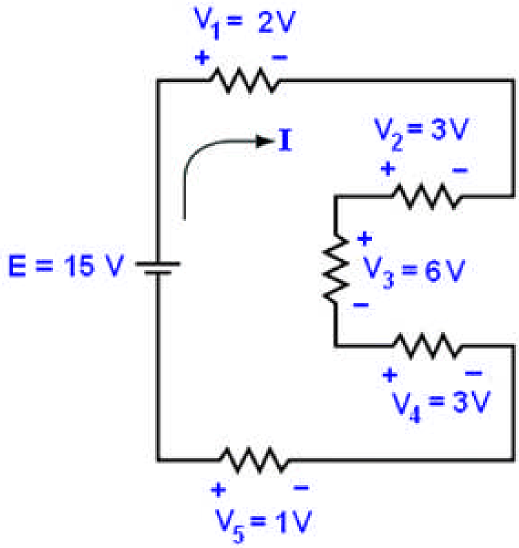

Fig. 1.2-13 Example 1.2-7

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EXAMPLE 1.2-8

Verify Kirchhoff s voltage law for the circuit of Fig. 1.2-14

SOLUTION

2V - 4V + 4V - 3.5 V - 1.5V + 3V = 0

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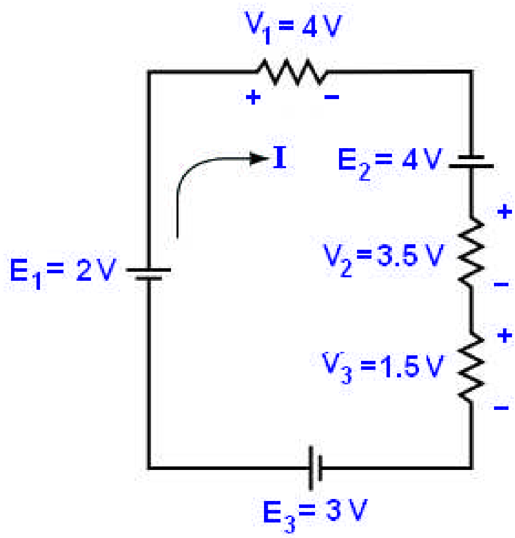

Fig. 1.2-14 Example 1.2-8

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KIRCHHOFF'S CURRENT LAW

Kirchhoff's current law is the underlying principle, which is used to explain the operation of a parallel circuit. Kirchhoff's current law states the following:

The summation of currents entering a node is equal to the summation of currents leaving the node.

In mathematical form, Kirchhoff s current law is stated as follows:

$$\sum \mathbf{I}_{\textbf{entering node}} = \sum \mathbf{I}_{\textbf{leaving node}}$$

Fig. 1.2-15 is an illustration of Kirchhoff's current law. Here we see that the node has two currents entering, $\mathbf{I_1 = 5\ A}$ and $\mathbf{I_5 = 3\ A}$, and three currents leaving, $\mathbf{I_2 = 2\ A}$, $\mathbf{I_3 = 4\ A}$, and $\mathbf{I_4, = 2\ A}$. Now we can see that:

$$\sum \mathbf{I_{in} = I_{out}}$$

5 A + 3 A = 2 A + 4 A + 2 A

8 A = 8 A (checks!)

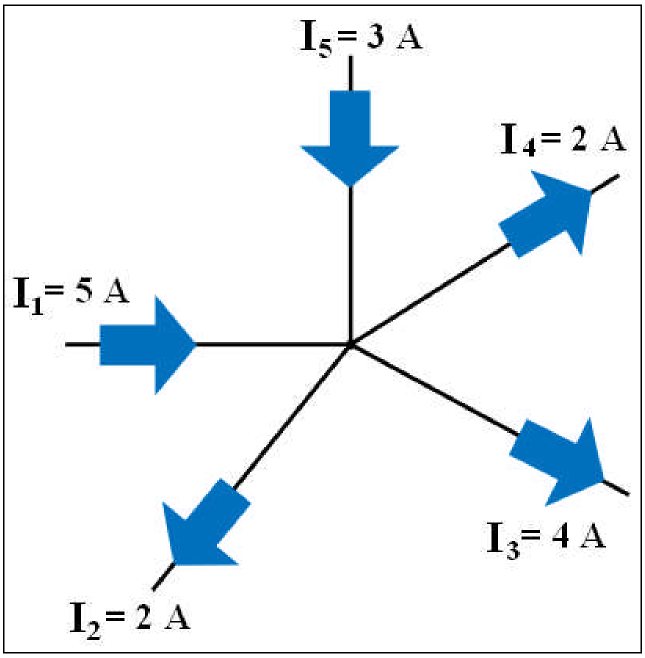


Fig. 1.2-15 Kirchhoff's current law

EXAMPLE 1.2-9

Verify Kirchhoff s current law for the circuit of Fig. 1.2-16

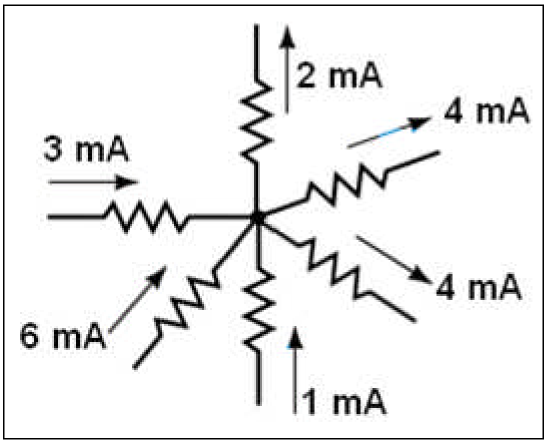


Fig. 1.2-16 Example 1.2-9

SOLUTION

3 mA + 6 mA + 1 mA = 2 mA + 4 mA + 4 mA

NOTE

Although that Kirchhoff's Laws appear simple, but these simple laws will prove to be powerful tools in working with complicated circuits.

CONVERSION Y TO Δ AND VICE VERSA

In the analysis of networks, it is often helpful to convert Δ to Y or vice versa (Fig. 1.2-17). Without the conversion, either it may be impossible to solve the circuit or the conversion makes the solution simpler. The formulas for these transformations are given here. Note that the letters are used as subscripts for R_A, R_B and R_C in the Δ while the resistances are numbered R_1, R_2 and R_3 in the Y.

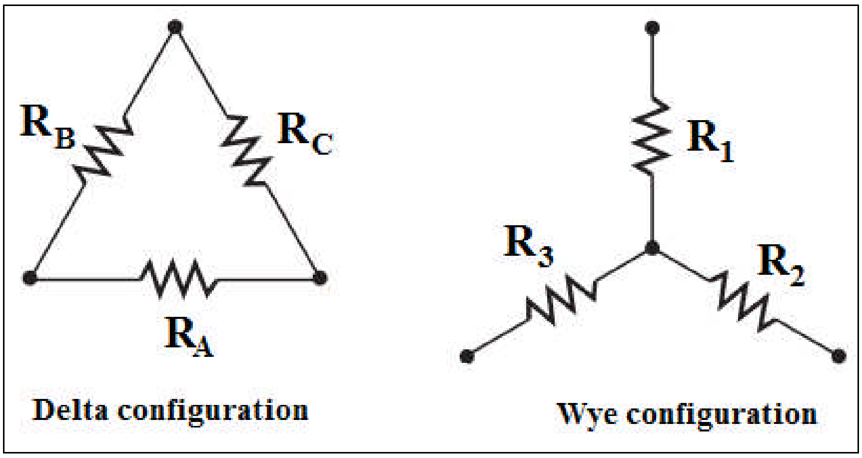


Fig. 1.2-17 Wye-Delta Transformation

CONVERSION FROM Y TO Δ

$R_A = \dfrac{R_1R_2 + R_2R_3 + R_3R_1}{R_1}$ $R_B = \dfrac{R_1R_2 + R_2R_3 + R_3R_1}{R_2}$ $R_C = \dfrac{R_1R_2 + R_2R_3 + R_3R_1}{R_3}$	$R_\Delta = \dfrac{\text{Sum of All Cross Products in (Y)}}{\text{Opposit (R) in (Y)}}$

CONVERSION OF Δ TO Y

$R_1 = \dfrac{R_BR_C}{R_A + R_B + R_C}$ $R_2 = \dfrac{R_CR_A}{R_A + R_B + R_C}$ $R_3 = \dfrac{R_AR_B}{R_A + R_B + R_C}$	$R_Y = \dfrac{\text{Product of Two Adjacent R in }(\Delta)}{\text{Sum of All (R) in }(\Delta)}$

EXAMPLE 1.2-10

If $R_A = 4\ \Omega$, $R_B = 6\ \Omega$, $R_C = 10\ \Omega$ in Δ, Give (Y) equivalent (R_1, R_2 and R_3).

SOLUTION

$$R_1 = \frac{R_B R_C}{R_A + R_B + R_C} = \frac{6 \times 10}{4 + 6 + 10} = \frac{60}{20} = 3\,\Omega$$

$$R_2 = \frac{R_C R_A}{R_A + R_B + R_C} = \frac{10 \times 4}{4 + 6 + 10} = \frac{40}{20} = 2\,\Omega$$

$$R_3 = \frac{R_A R_B}{R_A + R_B + R_C} = \frac{4 \times 6}{4 + 6 + 10} = \frac{24}{20} = 1.2\,\Omega$$

SUMMARY

- The current (Amperes) in an electric circuit equals the electromotive force or potential (volts) divided by the resistance (Ohms).
- Energy is the ability to do work while power is the rate at which work is done.
- In electrical circuits, energy is supplied by batteries or generators.
- Electrical energy is converted into various other forms of energy by components such as resistors (producing heat), loudspeakers (producing sound energy) and light emitting diodes (producing light).
- A wattmeter is connected It is basically a combination of an ammeter and a voltmeter, and it measures the product of current and voltage.
- Resistors have Ohm values and wattage ratings.
- Wattage rating indicates the maximum amount of power that a resistor can handle before it burns up.
- Never install a fuse or circuit breaker whose current rating is higher or whose voltage rating is lower than specified for a particular circuit.
- The total amount of power in a parallel resistive circuit is equal to the sum of the powers in each resistor in parallel.
- When two or more resistors are connected in series across a DC supply, different voltages appear across each resistor.

- The potential difference between any two points in a circuit is the difference in their respective voltages.
- Ground is simply "electrical point of reference" or "common point" (normally zero voltage) in a circuit.
- The chassis ground is usually further connected to the earth ground through a connection provided at the electrical outlet box.
- The earth ground is a connection which is bonded to the earth.
- The summation of voltage rises and voltage drops around a closed loop equal to zero.
- The summation of currents entering a node is equal to the summation of currents leaving the node.

FORMULAS

$V = I \times R$ $\quad$ $I = V/R$ $\quad$ and $\quad$ $R=V/I$

Where:

V = electromotive force or potential (V)

I = Electrical current (A)

R = Resistance (Ω)

$P = E/t$

Where: P = Power (W) $\quad$ E = Energy (J) $\quad$ t = time (seconds)

$P = I \times V$

Where: P = Power (W) $\quad$ I = Current (A) $\quad$ V = Voltage (V)

The formula may be arranged to make P. I or V the subject, as follows:

$P = I \times V$ $\quad$ $I = P/V$ $\quad$ and $\quad$ $V = P/I$

GLOSSSARY

Current	This is the flow of electrons in a conductor
Voltage	This is the electrical pressure causing the current to flow
Resistance	This is the opposition to the flow of current in a conductor determined by its length, cross-sectional area, and temperature
Power	The rate of doing work by electrons moving through a resistive material
Energy	The product of current and voltage
Electrocution	Killing by electric shock
Node	Point that currents entering and leaving it from different directions
Ground	A connection to the earth or to a conductive object such as an equipment chassis

REVIEW EXERCISE

1. Determine the current in each case.

a.- V= 5V, R= l Ω   b.- V = 15V, R= 10 Ω

c.- V= 50V, R= 100 Ω   d.- V= 30V, R= l5 k Ω

e.- V=250 V, R= 5 M Ω

2. If a resistor has 5.5 V across it and 3 mA flowing through it, what is the power?
3. An electric heater works on 115 V and draws 3 A of current. How much power does it use?
4. How much power is produced by 500 mA of current through a 4.7 kΩ resistor?
5. Calculate the power handled by a 10 k Ω resistor carrying 100μA.
6. A 50Ω resistor is connected across the terminals of a 1.5 V battery. What is the power dissipation in the resistor?
7. Find the total current produced by the battery in Fig. 1.2-18

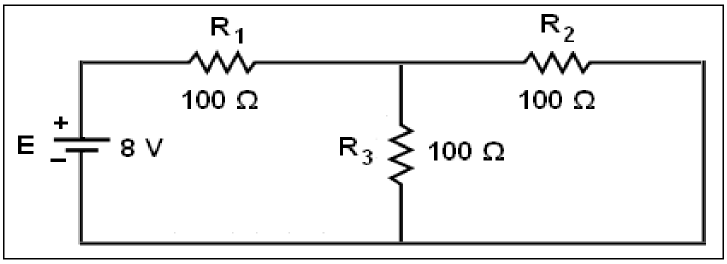


Fig. 1.2-18 Exercise 7

8. Determine for the unknown voltages in the circuit of Fig. 1.2-19

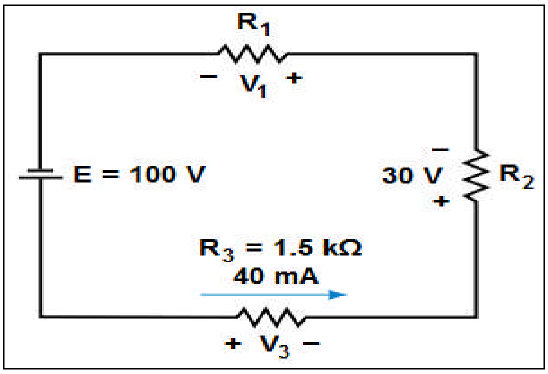


Fig. 1.2-19 Exercise 8

TASK 1.2-1

OHM'S LAW

OBJECTIVE

Upon completion of this task, the trainees will be able to:

- Verify Ohm's Law

EQUIPMENT AND MATERIALS REQUIRED

- 1 - ET-3100 Electronic Design Trainer or equivalent
- 1 - VOM Volt-Ohmmeter with leads
- 1 - 100 Ohm, 1% resistor
- 1 – 33 K Ohm, 1/2-watt resistor (orange-orange-orange-gold)
- 1 - 2 K Ohm, 1/2-watt resistor (red-black-red-gold)
- 1 - 100 K Ohm potentiometer (built into ET-3100)
- 1 - 1000 Ohm, 1% resistor

PROCEDURE

1. Using the Ohmmeter to measure the resistance of the 33 K Ohm, 5% resistor.
   The measured resistance is _________ K Ohms
   Is this value within the ±5% tolerance? Yes _____ No ______
2. Connect the voltmeter from the ground terminal to the positive terminal on the power supply. Adjust the + voltage control until the meter reads + 14 volts.
3. According to Ohm's law, **how much current should flow if the resistor value measured in Step 1 is placed across the voltage set in Step 2? ________ mA**

4. If the meter has current scales, connect the circuit shown in Fig. 1-1 and measure the current in the circuit. **The current is: ________ mA**

   If the meter does not have a current function, you will have to convert the voltmeter to a make shift ammeter. Construct the circuit shown in Fig. 1-2.

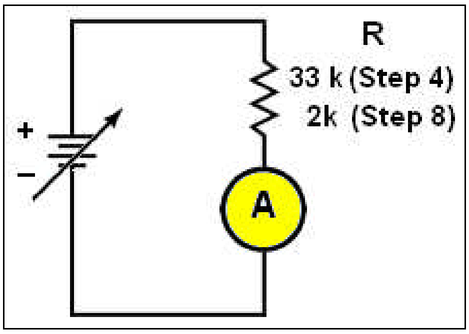


Fig. 1-1 Resistor Circuit for Steps 4 and 8

5. Notice that the voltmeter in parallel with the 1000 Ohm 1% resistor forms the makeshift ammeter. Recall that this arrangement converts the 0-1 volt scale to a 0-1 milli-Ampere scale. Using this makeshift ammeter, measure the current in the circuit.

   The current is: ________ mA

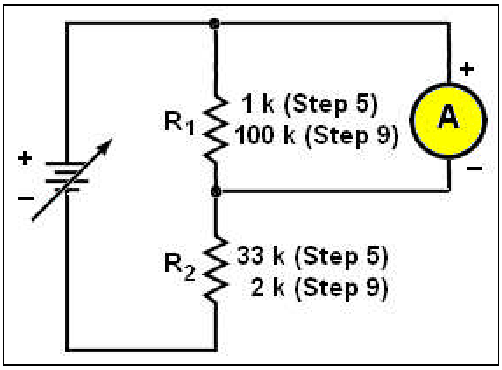


Fig. 1-2 Resistor Circuit for Steps 5 and 9

6. Does the value of current measured in **Step 4** (or **Step 5**) agree with the value that you computed in **Step 3** using Ohm's Law? **Yes** ________ **No** ________
7. Using the Ohmmeter, measure the resistance of the 2000 Ohm 5% resistor. The measured resistance is: ________ **Ohms**

   Is this within tolerance? Yes ________ No ________

8. If the meter has current scale, construct the circuit shown in Fig. 1-1 using 2000 Ohm resistor.
9. If the meter does not have current scales, use the 100 Ohm 1% resistor in conjunction with the voltmeter and construct the circuit shown in Fig. 1-2. The 100 Ohm resistor and the voltmeter are now connected as a makeshift ammeter. The 0-1 volt scale is now read as 0-10 milli-Amperes.
10. Adjust the + voltage control until the current through the circuit measures 6 mA.
11. Using the value of resistance measured in **Step 7** and the value of current set in **Step 10**, compute the value of voltage applied to the circuit.
    The computed voltage is: ________ Volts
12. Without touching the + voltage control, connect the voltmeter from the positive terminal to the ground terminal. **The measured voltage is: ________ Volts**
    Does this voltage agree with the value computed in step 11?
    Yes ________ No ________
13. Turn the shaft of 100K potentiometer all the way clockwise. Connect the voltmeter from the positive to the ground terminal of the power supply. Adjust the + voltage control until the meter reads 12 volts.
14. If the meter has current scales, construct the circuit shown in Fig. 1-3.

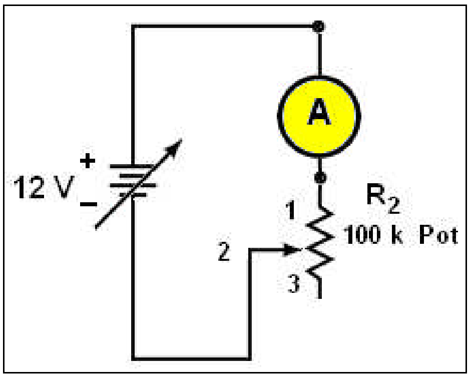


Fig. 1-3 Resistor Circuit for Steps 14

15. If the meter does not have current scales, construct the circuit shown in Fig. 1-4. Here, the 1000 Ohm 1% resistor and the voltmeter form a makeshift ammeter. Remember, the 0-1 volt scale is read as a 0-1 mA scale.

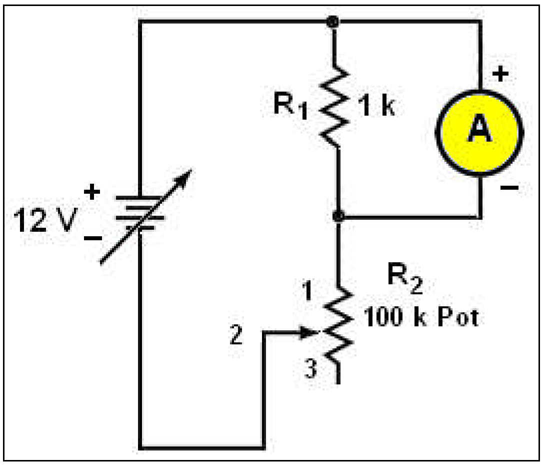


Fig. 1-4 Resistor Circuit for Steps 15

16. Turn the shaft of the 100 K Ohm potentiometer counterclockwise until the ammeter reads exactly 0.5 milli-Amperes.
17. Using the value of the voltage set in **Step 13** and the value of current set in **Step 16**, compute the value to which the potentiometer is presently set.

    The resistance is: ________ K Ohms
18. Without touching the shaft setting, disconnect the wires and leads from the 100 K Ohm potentiometer.
19. Using the Ohmmeter, measure the resistance between terminals 1 and 2 of the 100 K Ohm potentiometer. **The measured resistance is: ________KΩ**

    Does this reading agree with the value computed in Step 17?

    Yes ________ No ________

TASK 1.2-2

OHM'S LAW APPLICATIONS

OBJECTIVE

Upon completion of this task, the trainees will be able to:

- Investigate Ohm's Law applications in series-parallel circuits.

EQUIPMENT AND MATERIALS REQUIRED

- 1 - ET-3100 Trainer
- 2 - 1K Ohm resistors
- VOM Volt-Ohmmeter with leads
- 2 - 10K Ohm resistors

PROCEDURE

1. Construct the circuit shown in Fig. 2-1(a) on the ET-3100 Electronic Design Experimenter.

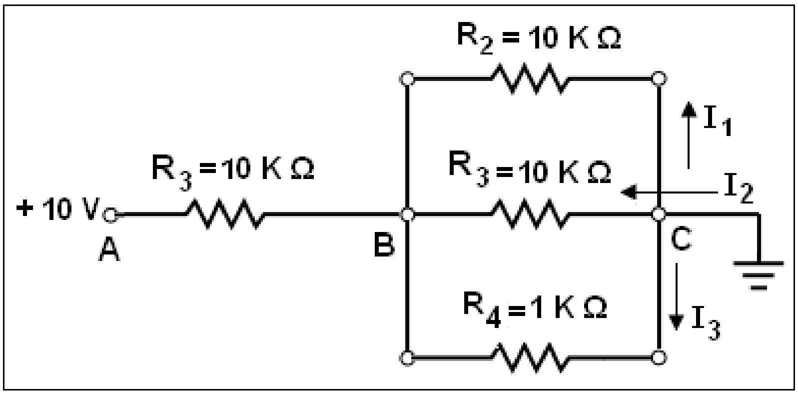


Fig. 2-1(a) Step 1

2. Connect the voltmeter from the GND terminal to the POS terminal on the Experimenter and adjust the + voltage to exactly +10 volts.

3. Connect the ammeter to the circuit between point C and ground, ensuring proper polarity.

   The current through the circuit is: ______ mA.

   Disconnect the ammeter from point C and reconnect point C directly to ground.

4. Now, using the voltage applied to the circuit and the total current through the circuit, use Ohm's law to calculate the total resistance of the circuit.

   The total resistance is: ______ Ohms.

5. Using the equations for resistance, calculate the resistance of the complete circuit. **R_T is: _____ Ohms**.

   Is there any difference between the total resistance calculated in Step 4 and the total resistance calculated in Step 5? Yes ______ No ______

   If so, why? __________

6. Use the nominal value of resistor R1, 1000 Ohms, and the current measured in **Step 3** to calculate the voltage drop across the resistor R1.

   The calculated voltage drop is: ______ Volts.

   Wire the test circuit like the one shown in Fig. 2-1(b). Do this by reversing the leads from the DC power supply. With the voltmeter, measure the voltage across R1. **The measured voltage is: ______ Volt**.

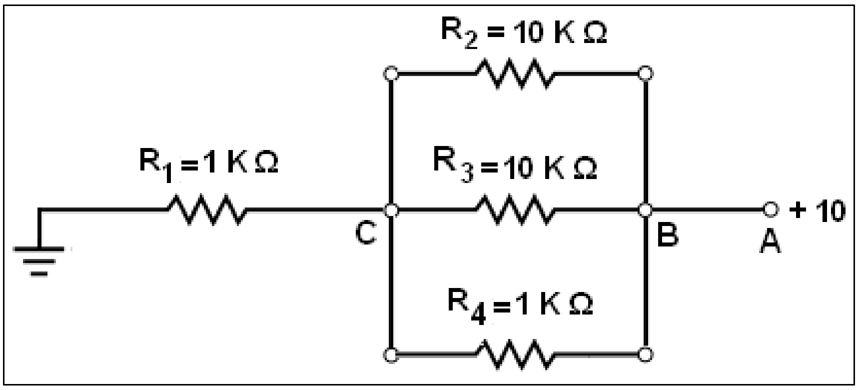


Fig. 2-1(b)

7. Now return the circuit to its original configuration, Fig. 2-1(a). Measure the voltage drop across the parallel network consisting of resistors R2, R3, and R4.

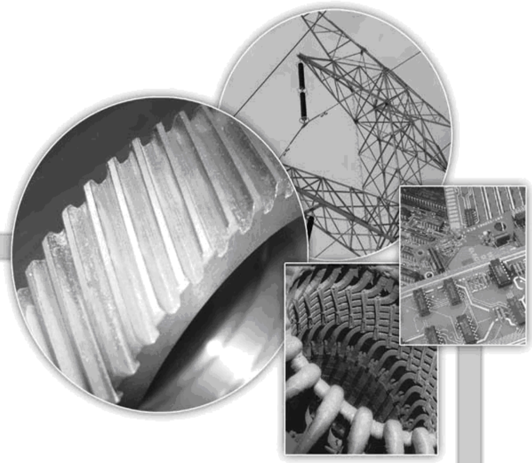
   The voltage drop across the parallel network is: ______ Volts.

8. Using the voltage drop measured across the parallel network and the nominal value of resistors R2, R3 and R4, determine the current through each of the branches. **The branch currents are: I_1 = ______ mA I_2 = ______ mA I_3 = ______ mA**

   Is total current approximately the same as the sum of the three calculated branch currents? Yes ______ No ______

9. Making sure to observe proper polarity connect the ammeter in series with R2, then R3 and then R4 and record their branch currents:

   I_1 = ______ mA I_2 = ______ mA I_3 = ______ mA



LESSON 1.3

ELECTRICAL MEASURING INSTRUMENTS

LESSON 1.3

ELECTRICAL MEASURING INSTRUMENTS

OVERVEIW

In this lesson, the trainees learn how to use measuring instruments in the field for AC/DC measurements.

OBJECTIVES

Upon completion of this lesson, the trainees will be able to familiarize and use:

- Digital multimeter.
- Analogue multimeter.
- Function generator.
- Frequency counter.
- Megger.
- Clamp-on meter.
- Phase sequence meter.
- Power system polymeter.
- Phase angle meter.
- Frequency counter.
- Function generator.

Task 1.3-1: Voltmeter Sensitivity

Task 1.3-2: Voltmeter Loading Effects

Task 1.3-3: Phase Sequence Meter

Task 1.3-4: Polymeter

Task 1.3-5: Phase Angle Meter

Task 1.3-6: Frequency Meter

DIGITAL MULTIMETERS

Digital multimeters (Fig. 1.3-1) measure analog quantities and convert them to numbers on numerical display (readout).

Fig. 1.3-1 Portable Digital Measuring Devices

The digital multimeter (Fig. 1.3-2) is ideally suited for application in the field, lab and shop. It can be used to make accurate measurements of:

- AC and DC volts
- DC current
- Resistance
- Continuity

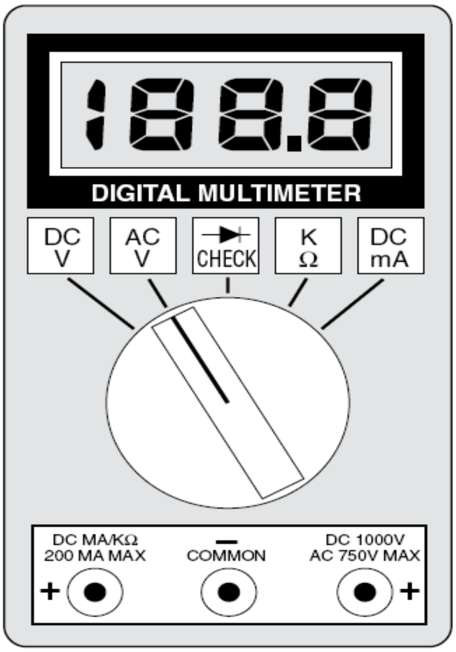


Fig. 1.3-2 Digital Multimeter

USING DIGITAL MULTIMETERS

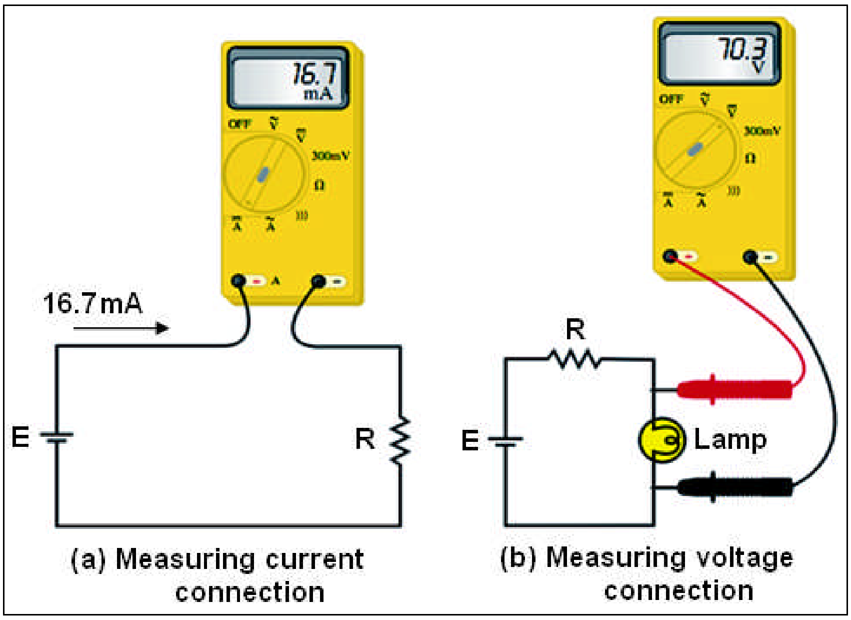


Fig. 1.3-3 Measuring Current and Voltage

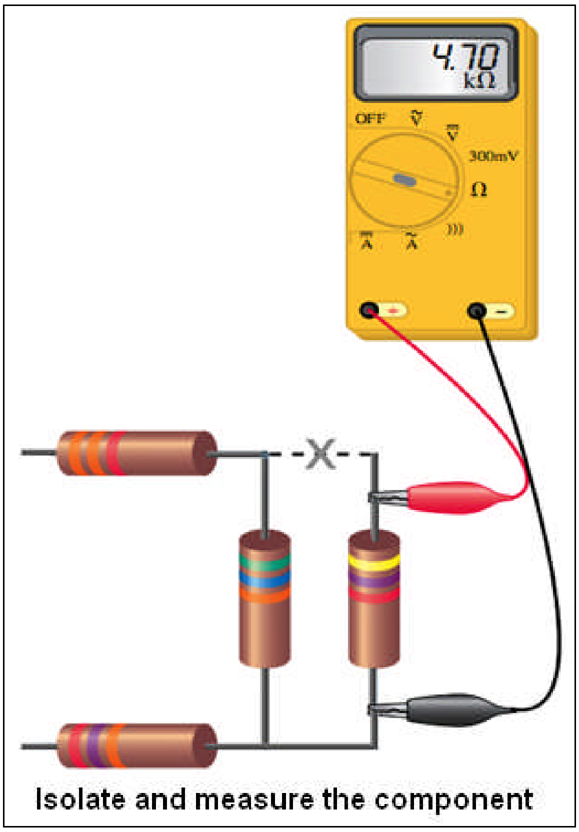


Fig. 1.3-4 Measuring Resistance

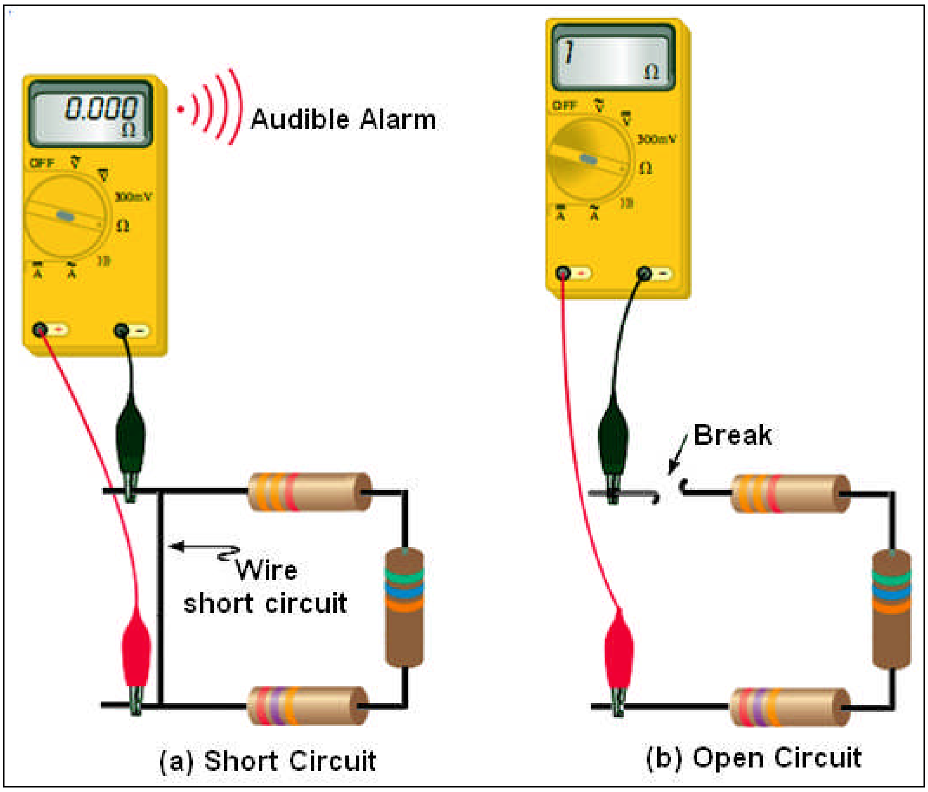


Fig. 1.3-5 Checking Short and Open Circuits

THE MEGGER

An ordinary Ohmmeter cannot be used for measuring resistance of many millions of Ohms, such as resistance of insulation for the conductor or piece of equipment. It is necessary to use a much higher potential than is furnished by an Ohmmeter battery. The megger is used for measuring the insulation resistance and it contains a hand driven D.C. generator and moving coil instrument, which indicates the value of resistance being measured. The meter face has scales calibrated in both Ohms and mega Ohms.

The parts of hand crank megger are (Fig. 1.3-6):

1.- Crank	2.- Range Switch
3.- Meter Face	4.- Terminals

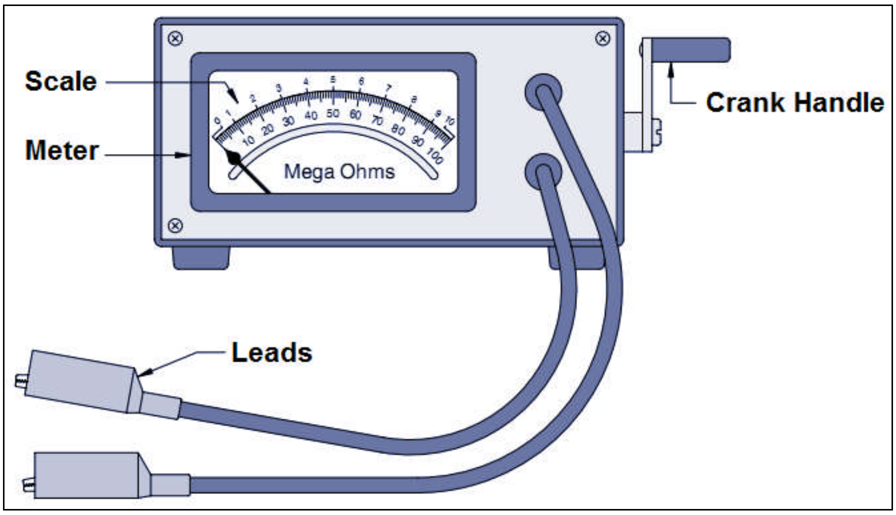


Fig. 1.3-6 Insulation Tester (Megger)

The crank turns the generator that supplies the voltage necessary for resistance measurements.

Meggers (Fig. 1.3-6, 7, 8) are available with voltage ratings ranging from **l00** to **5000** volts. Testing the megger to measure insulation, it must be adjusted to zero reading at first. Meggers can commonly be divided into three general types, those with hand-cranked generator, motor driven megger and battery operated megger.

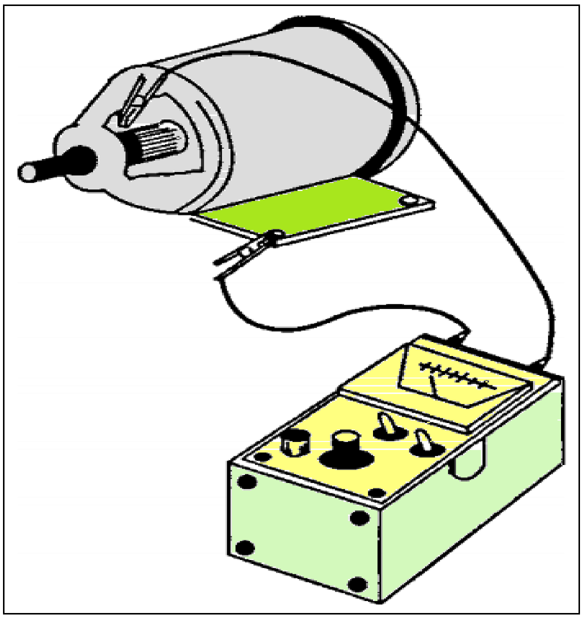


Fig. 1.3-7 Megger Connections for Testing DC Motors and Generators

Fig. 1.3-8 Modern Version of Megger Insulation Tester

RULES THAT MUST BE FOLLOWED BY RELAY TECHNICIAN WHEN MAKING MEGGER TESTS:

1. Make sure the equipment to be tested is not energized and that it is disconnected from all other equipment and circuits.
2. Be aware that the megger is capable to develop severe shock voltages. Being careful, he must not hold the bar contact part of the test lead while the megger is being cranked.

MEASURING TRANSFORMER WINDING INSULATION

No material is a perfect insulator and all insulation is subject to deterioration. The purpose of electrical insulation is to make sure that the current that flows through a piece of electrical equipment does not go where it is not supposed to. Among the factors that affect the amount of resistance in insulation are its type and thickness; which are determined when the equipment is manufactured.

The megger **(**Fig. 1.3-9**)** is used to check the transformer winding insulation. Minimum safe insulation resistance values (in Ohms or Mega Ohms) at different temperatures are usually specified for different voltage ratings of the transformers by

manufacturers. Each winding is tested separately to the ground. If all windings indicate lower than acceptable resistance values, but approximately proportionally equal, it may be that moisture has entered the winding insulation. The windings may require drying out.

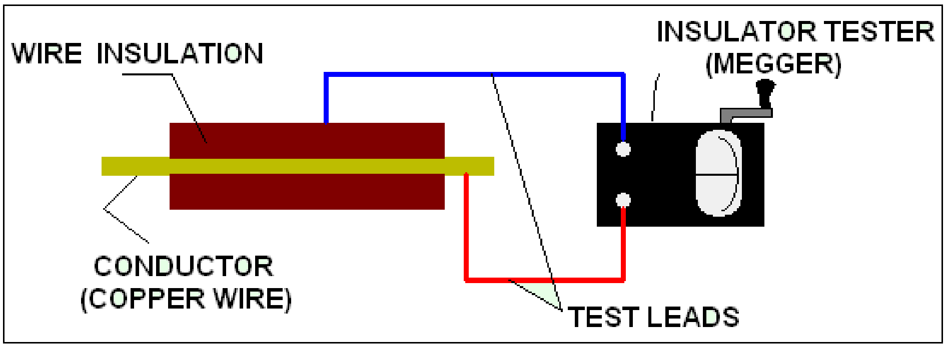


Fig. 1.3-9 Typical Megger Hook-Up to Measure Insulation Resistance

CLAMP-ON AMMETER

A Clamp-On Ammeter is used to measure currents in AC circuits. The advantage is that no disconnection of circuits is done to use this meter. Fig. 1.3-10 shows a Clamp-On Ammeter and Fig. 1.3-11 shows how it is used.

In a circuit with a live (hot) conductor and a neutral (ground) conductor, if both the conductors are passed through the core, the ammeter will show zero reading. The reason is, the directions of currents in the two conductors are opposite and the magnetic flux produced by each conductor cancels the flux by the other. As a result, there is no current induced in the coil.

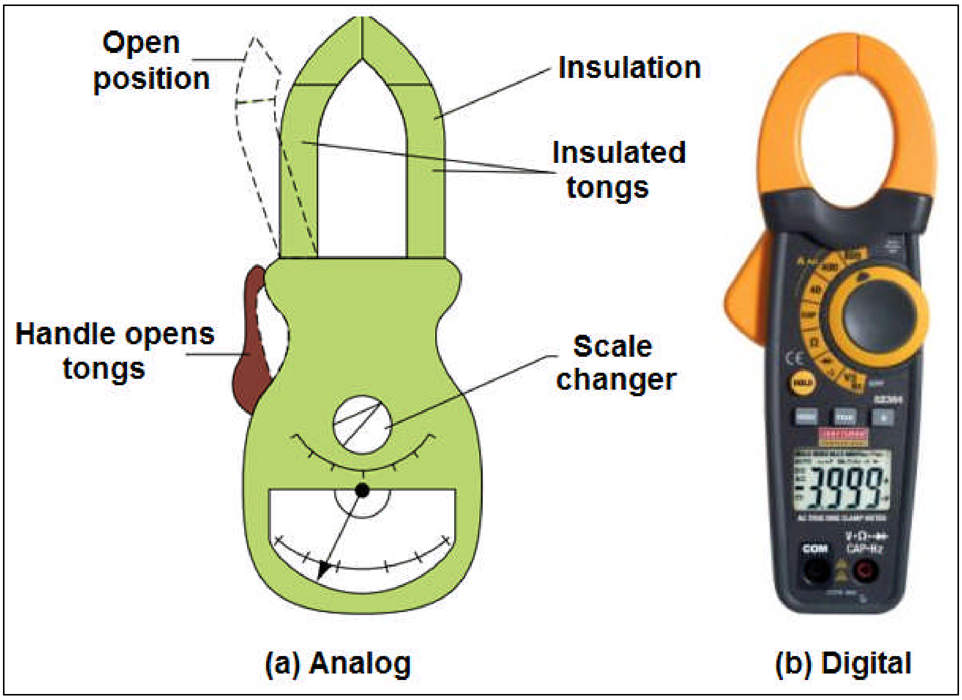


Fig. 1.3-10 Clamp-On Ammeter

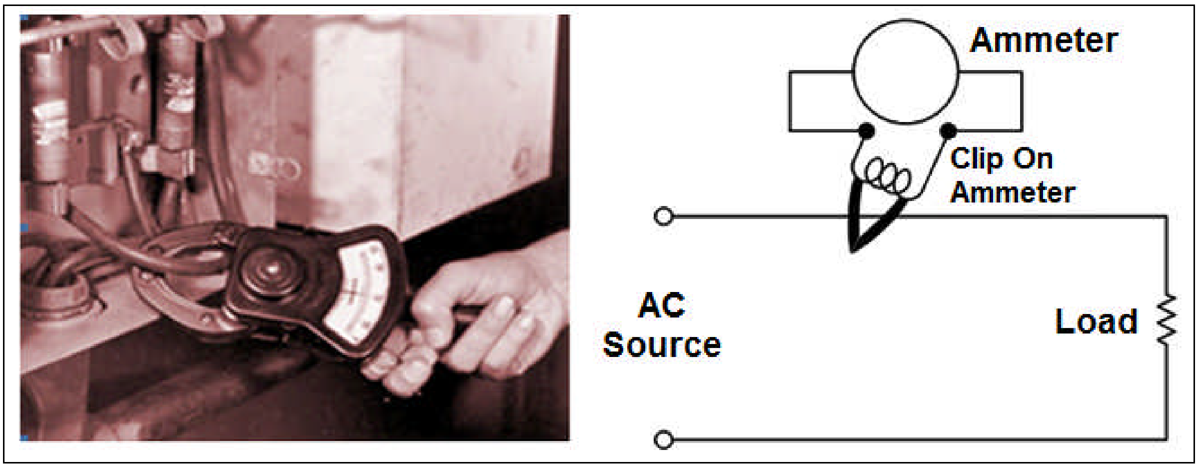


Fig. 1.3-11 Using Clamp-On Ammeter

PHASE SEQUENCE METER

The three phase source has three sine wave voltages differing in phase by 120°. The order in which the three voltages succeed one another is called phase sequence or phase rotation (Fig. 1.3-12), determined by the direction of alternator rotation.

Fig. 1.3-12 Phase Sequence Meter

The three output lines carrying these phase voltages are usually identified by the letters **R**, **S**, and **T**, so that the clockwise rotation the phase sequence is **RST**, and with counter-clockwise rotation it is TSR. Interchanging any two of the phases will reverse the phase sequence.

<table>
<tr>
<td>Phase sequence meter (Fig. 1.3-13) identifies phase sequence and indicates any open phase. This instrument gives instant reading of phase sequence indication</td>
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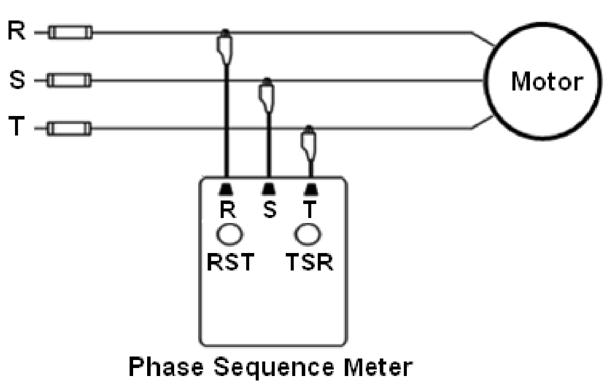

Fig. 1.3-13 Phase Sequence Meter Connection
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</table>

If the phase sequence indicator properly connected, the **RST** or **TSR** light will indicate the phase sequence, and all three of the phase lights will glow to show that three phase voltages are present.

If there is an open phase or open connection to the phase sequence indicator, only one of the three phase lights will glow and will indicate which phase is open.

PHASE ANGLE METER

A phase-meter is a direct-reading device, which measures phase angle between two voltages, two currents or voltage and current. The phase-meter has self check features and indicators, which inform the operator when an input signal level is out of range for a measurement.

SPECIFICATIONS OF PHASE ANGLE METER

The phase-meter is specifically tailored to meet requirements of power system applications. A phase-meter has an angle range of **0°** to **360°** within the frequency range of **57** to **63** Hz. Input voltage can be measured between **1** to **30** voltages and **20** to **600** volts at an accuracy of **0.5**°. Input current ranges from **0.05** to **1.5** and **1.5** to **50** Amperes with the same accuracy. The meter can display readings in four digits and has the ability to hold last reading.

Digital phase angle meter (Fig. 1.3-14) is designed to test for example directional protection relays and to conduct directional tests on instrument transformers.

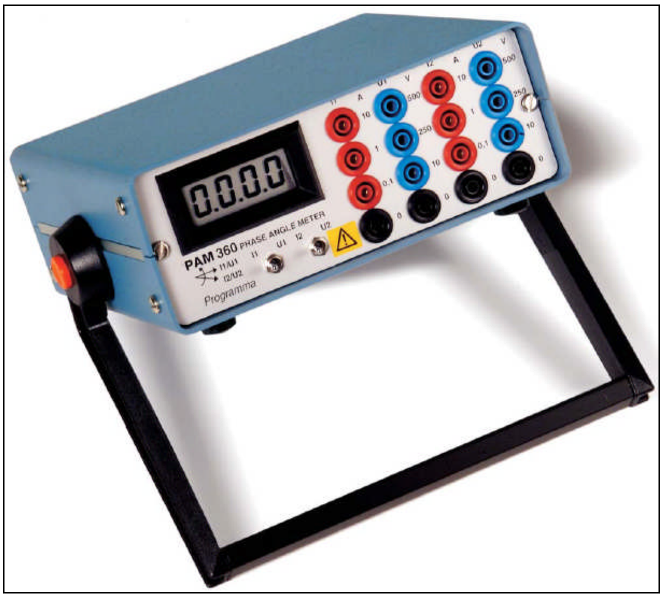


Fig. 1.3-14 Digital Phase Angle Meter

POWER SYSTEM POLYMETER

The polymeter (Fig. 1.3-15) measures two simultaneous independent measurements of:

1.- Voltage and current
2.- Voltage and voltage
3.- Voltage and time or cycles
4.- Voltage and frequency
5.- Current and current
6.- Current and time or cycles
7.- Current and frequency
8.- Time and frequency

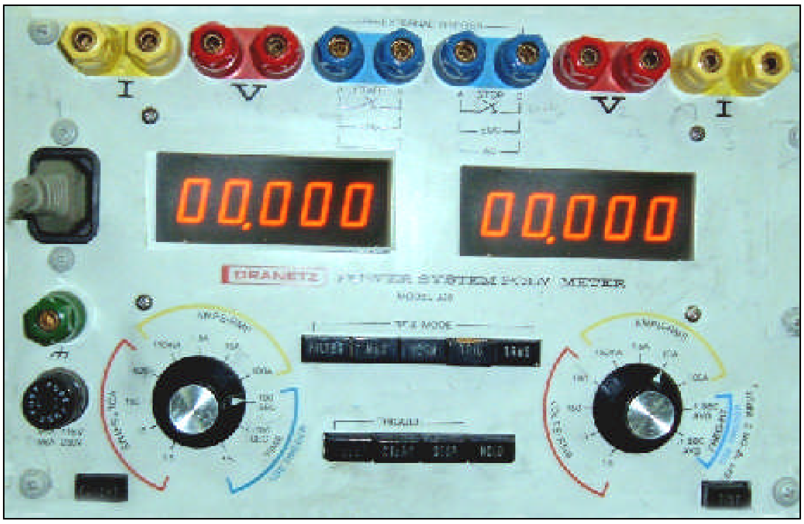


Fig. 1.3-15 Polymeter

The instrument operates in continuous or triggered mode and holds the last reading of the maximum voltage or current reading. The readout is from dual high-resolution 6-digit displays. Both input circuits are fully isolated from the internal circuits and from each other.

FREQUENCY COUNTER

In some applications, principally radio frequency (RF) and digital, it is necessary to determine the frequency at which a circuit is operating. In these cases a frequency counter (Fig. 1.3-16) is used. These instruments generally have an LED (light emitting

diode) display that provides a direct frequency reading. Fig. 1.3-17 shows digital Frequency Counter.

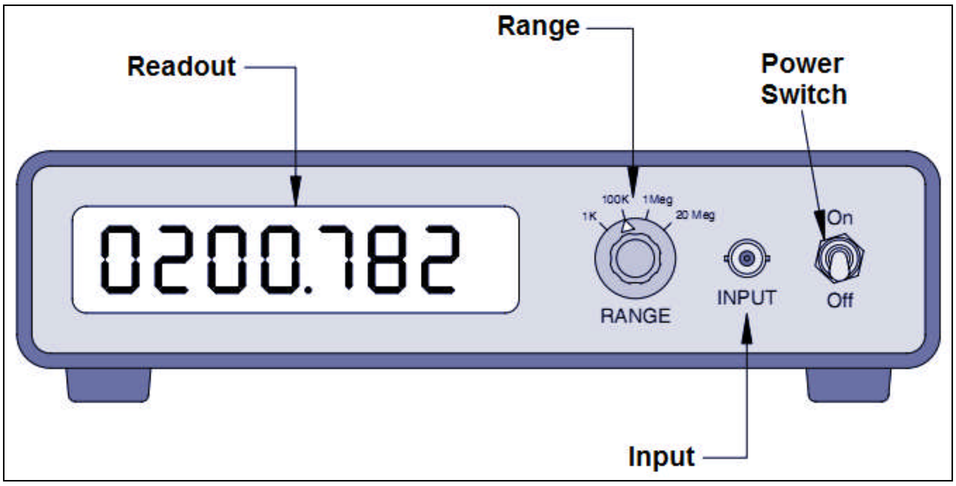


Fig. 1.3-16 Frequency Counter

Fig. 1.3-17 Digital Frequency Counter

FUNCTION GENERATOR

Function generator (Fig. 1.3-18) is used in the electronic instrumentation laboratory to generate low frequency signal with different wave shapes, including sine wave and square waveforms in a single instrument. It is sometimes called waveform generator, Fig. 1.3-19 shows digital Function Generator.

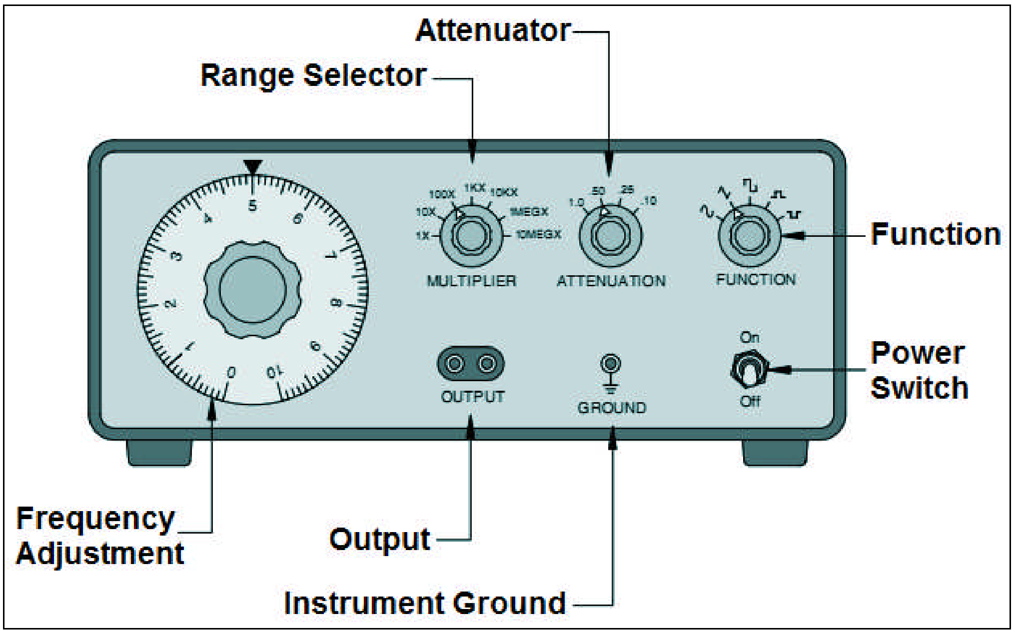


Fig. 1.3-18 Function Generator

Fig.1.3-19 Digital Function Generator

SUMMARY

- Digital multimeters measure analog quantities and convert them to numbers on numerical display (or readout).
- The digital multimeter can be used to make accurate measurements of AC and DC volts, DC current, Resistance and Continuity.
- The megger is used for measuring the insulation resistance.

- Before using the megger to measure insulation, it must be adjusted to zero reading at first.
- No material is a perfect insulator and all insulation is subject to deterioration.
- A clamp-on ammeter is used to measure currents in AC circuits without disconnection of the circuit.
- A phase angle meter is a direct-reading device, which measures phase angle between two voltages, two currents or voltage and current.
- The phase sequence meter is specifically tailored to meet requirements of power system applications.
- The polymeter measures two simultaneous independent measurements.
- Frequency counter is capable for measuring the frequency accurately and it may also be used in period measurements.
- Function generator is used in the electronic instrumentation laboratory to generate low frequency signal with different wave shapes.

GLOSSARY

Ammeter	A meter designed to measure current
Voltmeter	A meter designed to measure voltage
Insulator	A material with a high resistance to the flow of electrons. Plastic, rubber, glass, and mica are examples of materials that are good insulators
Short circuit	A normally unintended low resistance path for current
Deterioration	Weakening, Drop, Fall
Moisture	Humidity, Dryness
RF	Radio frequency
LED	Light emitting diode
Function generator	Using in the electronic instrumentation laboratory to generate low frequency signal with different wave shapes

REVIEW EXERCISE

Choose the correct answer:

1. ____________is used to measure currents in ac circuits without disconnection of the circuit.

   a.- Megger b.- Digital Multimeter

   c.- Clamp-On Ammeter d.- Ammeter

2. Before using the Megger to check the ___________ of a transformer, the Technician should make sure that the transformer is not energized and disconnected from all other equipment and circuits.

   a.- voltage b.- load

   c.- insulation resistance d.- phase sequence

3. Measure analog quantities and convert them to numbers on numerical display.

   a.- Analog Multimeters b.- Digital Multimeters

   c.- Transformers d.- Breakers

4. The _______________ contains a hand driven D.C. generator and moving coil instrument which indicates the value of resistance being measured.

   a.- voltmeter b.- digital Multimeter

   c.- clamp-on ammeter d.- megger

Complete by filling in blanks:

5. The hand crank megger parts are:

   1. ____________ 2. ____________ 3. __________ 4. ____________

6. Before using the megger to measure insulation, it must be adjusted to ____ reading at first.
7. The phase sequence meter is specifically tailored to meet requirements of ________ applications.
8. A phase-meter is a direct-reading device, which measures _______ between two voltages, two currents or voltage and current.
9. The polymeter measures two simultaneous __________ measurements.

10. Function generator is used in the electronic instrumentation laboratory to ______ low frequency signal with different ______________.
11. Frequency counter is capable for measuring the _____ accurately and it may also be used in ______ measurements.

12. Match the left and right columns shown below:

A Megger	a) Easy to use and it displays the digital value of the measurement with decimal point, polarity and the unit
Check infinity of the megger	b) It can be used to measure the insulation resistance of a circuit or a piece of equipment
DMM	c) The pointer should read ∞ when the switch is set to any position except Ω or discharge. With no leads connected to the terminals, by hand cranking
Megger 0 check	d) Identifies phase sequence and indicates any open phase
Phase sequence meter	e) The pointer should read zero with hand cranking when the switch is set to any position except discharge and short circuit ground and line leads.

13. Check True for the correct sentence and False for the wrong sentence:

	T	**F**
a.- In a circuit with a live conductor and a neutral conductor, if both the conductors are passed through the core, the clamp-ammeter will show zero reading		
b.- Never use a megger on an energized circuit..		
c.- A clamp-on ammeter is used to measure currents in AC circuits with disconnection of circuits is done to use this meter.		

TASK 1.3-1

VOLTMETER SENSITIVITY

OBJECTIVES

Upon completion of this task, the trainees will be able to:

- Determine, experimentally, the Ohms per Volt Sensitivity of a Voltmeter.

EQUIPMENT AND MATERIALS REQUIRED

- 1 - Voltmeter with test leads
- 1– VOM Volt-Ohmmeter

PROCEDURE

1. The simplest way to determine the resistance of the Voltmeter is to measure it directly with a separate Ohmmeter.
2. Place the Voltmeter on one of the middle DCV ranges.
3. Zero the Ohmmeter.
4. Connect the Ohmmeter across the Voltmeter leads.
5. Record the resistance of the Voltmeter. **Rv** = _____Ω
6. Place the Voltmeter on the next highest DCV range.
7. Measure and record the resistance. **Rv** = _____Ω
8. If the resistance readings recorded in **Step 5** and **7** are very high and are the same in both cases, the Voltmeter is one of the electronic types. Verify this by measuring the resistance on other DC voltage ranges. Be careful on the lower voltage ranges that you do not damage the Voltmeter needle.

   The resistance on all ranges is: ______ Ohms

9. If the resistance reading recorded in Step 5 is considerably lower than that recorded in Step 7, the Voltmeter is not one of the electronic types and its Ohms per Volt rating can be determined.
10. Determine its Ohms per Volt rating by dividing the resistance recorded in **Step 5** by the Full-Scale voltage reading.

    The Ohms per Volt rating of the Voltmeter is: ______Ohms per Volt
11. Verify this by dividing the resistance recorded in **Step 7** by the Full-Scale voltage range used. The Ohms per Volt rating should be the same.

TASK 1.3-2

VOLTMETER LOADING EFFECTS

OBJECTIVES

Upon completion of this task, the trainees will be able to:

- Determine, experimentally, the Loading effects of a Voltmeter.

EQUIPMENT

- 1 - ET-3100 Electronic Design Trainer
- 1 - Voltmeter with test leads
- 1 - 100Ω, 1/2 Watt, 1% resistor.
- 1 - 220K, 1/2 Watt resistor (red-red-yellow-gold)
- 1 - 1M, 1/2 Watt resistor (brown-black-green-gold)
- 1 - 10M, 1/2 Watt resistor (brown-black-blue-silver)
- 1 - 1K potentiometer (built into ET-3100)

PROCEDURE

1. Measure the resistance of the 100Ω, 1/2-watt, 1% resistor using the Ohmmeter. Note the reading on the Ohmmeter.
2. Connect the Ohmmeter from an end terminal to the center terminal of the 1K potentiometer.
3. Adjust the 1K potentiometer until the Ohmmeter reads the exact resistance measured in **Step 1**. The 1K potentiometer is now set to the same value as the 100K, 1% resistor.

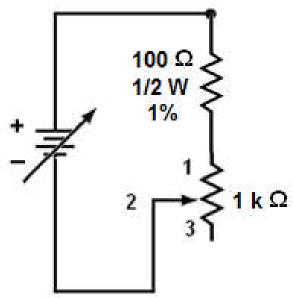
<table>
<tr><td>4. Without disturbing the potentiometer setting, connect the circuit (Fig. 2-1).</td><td>

Fig. 2-1 100Ω Potentiometer Setting</td></tr>
</table>

5. Connect the Voltmeter from the positive to ground terminals and adjust the + voltage for a reading of exactly 10V.
6. Measure the voltage drop across the 100Ω, 1% resistor.

   The voltage drop is: ______V
7. Measure the voltage drop across the terminals marked 1 and 2 of the 1K potentiometer (Fig. 2-2).

   The voltage, V_{12}: ______V
8. Add the voltage measured in **Step 6** to that measured in **Step 7**.

   Do the two voltages add up to the value set in Step 5? Yes ____ No ____

   Are there any signs of Voltmeter loading in the above steps? Yes ___ No ___
9. Connect the circuit (Fig. 2-2).

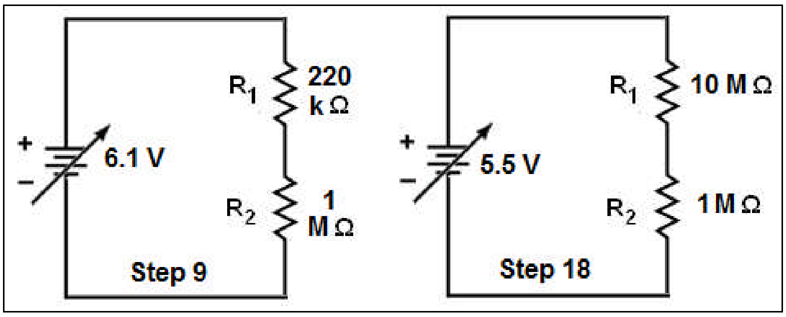


Fig. 2-2 Voltmeter Loading Demonstration

10. Connect the Voltmeter from the positive to the ground terminals of the power supply and set the + voltage so that the Voltmeter reads 6.1V.
11. Using Ohm's law, compute the current flowing in the circuit.

    The current, I: ______μA

12. Using Ohm's law, compute the voltage drop across the 200 K (**R1**) resistors.

    E_{R1} = ______V

13. Using Ohm's law, compute the voltage drop across the 1M **(R2)** resistor.

    E_{R2} = ______V

14. Add E_{R1} to E_{R2}.

    Does the total equal the source voltage of 6.1V? Yes ____ No ____

15. Using the Voltmeter, measure the voltage drop across R1. **E_{R1} = ______V**

16. Measure the voltage drop across R2. **E_{R2} = ______V**

17. Add the measured value of E_{R1} to the measured value of E_{R2}.

    Does the total equal the source voltage of 6.1V? Yes ____ No ____

    If not, how do you account for the inaccuracy?

    ____

18. In order to demonstrate loading by the electronic type meter, higher values of resistors must be used. Replace the 220 K resistor with a 10M resistor.

19. Set the applied voltage to 5.5V.

20. Compute the current in the circuit. **I = ______μA**

21. Compute the voltage drop across R1.

    E_{R1} = ______V

22. Compute the voltage drop across R2

    E_{R2} = ______V

23. Add E_{R1} to E_{R2}.

    Does the total equal the applied voltage of 5.5 volts? Yes ____ No ____

24. Measure the voltage drop across R1.

    E_{R1} = ______V

    Is this approximately the same as the computed value? Yes ____ No ____

25. Measure the voltage drop across R2.

    E_{R2} = ______V

    Is this approximately the same as the computed value? Yes ____ No ____

26. Add the measured values of E_{R1} and E_{R2}.

    Does the total equal the applied voltage of 5.5V? Yes ____ No ____

TASK 1.3-3

PHASE SEQUENCE METER

OBJECTIVES

Upon completion of this task, the trainees will be able to:

- Determine The Phase Sequence of 3 Phase Voltage Supply.

TOOLS AND EQUIPMENT

- 3Ø Phase Supply.
- Phase sequence Meter.

PROCEDURE

1. Connect the three leads across the three phase circuit in any sequence.
2. Read phase sequence. The **RST** or **TSR** lamp will glow showing phase sequence
3. Detect open phase. The **R**, **S**, or **T** phase lamp glows to indicate an open phase, open test lead, or no contact of test clip (Fig. 3-1).

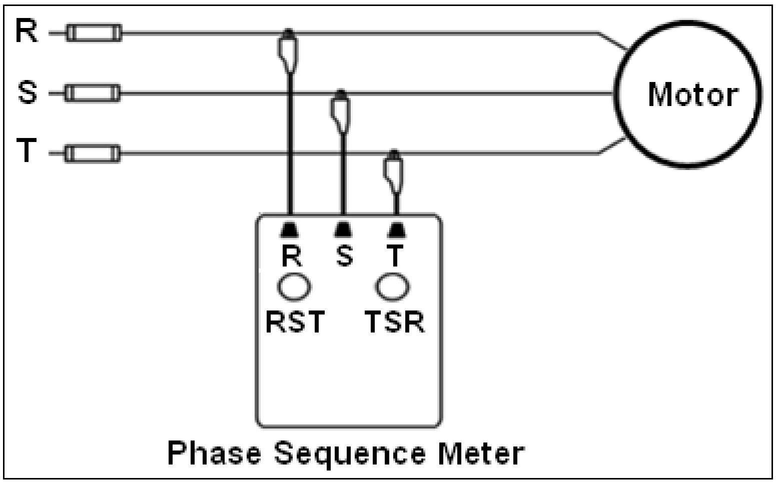


Fig. 3-1 Phase Sequence Meter

TASK 1.3-4

POLYMETER

OBJECTIVES

Upon completion of this task, the trainees will be able to:

- Measure two separate voltage and current sources using the Polymeter.

EQUIPMENT AND MATERIALS

- 1 – Polymeter Model 325
- 2 – Voltage Sources
- 1 – AC Load (motor/lamp/resistor)

PROCEDURE

1. Receive from your Instructor the following:
   - Polymeter Model 325 (DRANETZ).
   - Two voltage sources AC.
   - Load (motors or lamps or resistors)
2. Connect safety ground terminal to an effective earth point.

NOTE

Earthing the meter eliminates any shock hazard when working with input voltages exceeding 30 volts rms. Use a wire size capable of carrying the rated current from the signal source.

3. Connect the power cord between the power source input power connector and push power switch to **ON** position.
4. Connect the voltage source #1 to the left channel (6).

NOTE

a ***If a high voltage is anticipated, set the Mode/Range switch to the corresponding input range before applying the input voltage.***

b. Be sure that the lead insulation is sufficient and that excessive bare wire ends can not accidentally contact the front panel or c

5. Use the other voltage channel to measure the voltage of source #2.

MEASURE THE CURRENTS

6. Connect the voltage source #1 to a load (lamps, etc.).
7. Connect the two leads breaking the circuit into channel 1 for current. The meter is in series with the circuit.
8. Switch ON the power supply.
9. Read the current in the current channel (5).

MEASURING ELAPSED CYCLES OF POWER LINE FREQUENCY

10. Set left channel Mode/Range switch to TIME position.
11. Press Trigger Reset Push-button, apply start/stop and read the cycles on the left display.

NOTE

c. The left display will show elapsed cycles between the applied start/stop TRIG.

d. To display the time elapsed, use Reset (18), Start (19), Stop (20) sequence to measure the time.

MEASURING FREQUENCY

12. Connect the input signal to the left channel voltage or current terminals.

13. Set the left Mode/Range switch to the correct range for the input level, keeping the input level between 1/10th of the full scale reading.
14. Set the right Mode/Range switch to the desired Frequency scale.

NOTE

The frequency meter will then track the input frequency between the Start Trigger and the Stop Trigger input and will display the last frequency measurement until the Reset Push-button is pressed again. Note that the front panel Start/Stop Push-buttons may be used in lieu of external signal.

MEASURING TIME VERSUS FREQUENCY

15. Connect rms voltage to the left channel (**V**) terminal.

NOTE

RMS voltage is at least 20 or 30 volts in amplitude.

16. Set the left mode/range switch to the desired Time position.
17. Set the right mode/range switch to the desired Frequency position.
18. Press Trigger Reset and Start/Stop Push-buttons.

NOTE

The left and right channels will display the time and input frequency, respectively, between the START TRIGG and the STOP TRIGG and will display the last measurement until the RESET Push-button is depressed again. Note that the front panel START AND STOP Push-buttons may be used in lieu of external signals.

TASK 1.3-5
PHASE ANGLE METER

OBJECTIVES

Upon completion of this task, the trainees will be able to

- Measure the Phase Angle using Phase Angle Meter.

EQUIPMENT AND MATERIALS

- 1 - Phase Angle Meter, Model 314
- 2 – Capacitors
- 2 - Variable resistor
- 2 – AC Power sources

PROCEDURE

1. Receive from your Instructor the following:
   a. Phase angle meter, Model 314 (DRANETZ)
   b. Variable resistors.
   c. Capacitors.
   d. Variable voltage supplies or two voltages from separate sources.
2. Connect Safety Ground terminal to an effective earth ground point to eliminate any shock hazard when working with input voltages exceeding 30 volts. Use a wire size capable of carrying the full output of the signal source.
3. Connect power cord between power source and input power connector.

NOTE

Unless otherwise indicated, the phase-meter is shipped to operate at 115 volts. If required, the phase-meter can operate on a range of power line voltage by setting switches on circuit board. Improper voltage supply may result in personal injury and/or damage to equipment.

4. Turn "POWER" switch to "ON"
5. Connect input signals (Fig. 5-1) to the appropriate terminals for both circuit #1 and #2. Each group of 3 input terminals is isolated from the instrument case and from all other terminals. This allows the operator complete freedom to use any polarity of each input signal. To serve as a guide and test purpose call instructor to choose for you one of the following examples of typical connections and inputs. Do not connect more than one input to either input circuit. For example, a current and a voltage may not be simultaneously connected to the same circuit #1. All unused input terminals must remain unconnected. Do not connect a voltage source across a pair of current input terminals. This will place very low impedance across the voltage source causing damage either to the source or phase-meter.
6. Energize inputs allowing phase reading to stabilize. Digital display should now indicate angle by which circuit #2 leads circuit #1. Alternately, consider angle displayed to be that by which circuit #1 lags circuit #2.
7. Hold reading. (Refer to information Sheet).
8. Record reading.
9. Return Hold switch to normal.
10. De-energize inputs.
11. Disconnect inputs.
12. Shut off power to meter.
13. Disconnect power.
14. Clean area and return equipment.

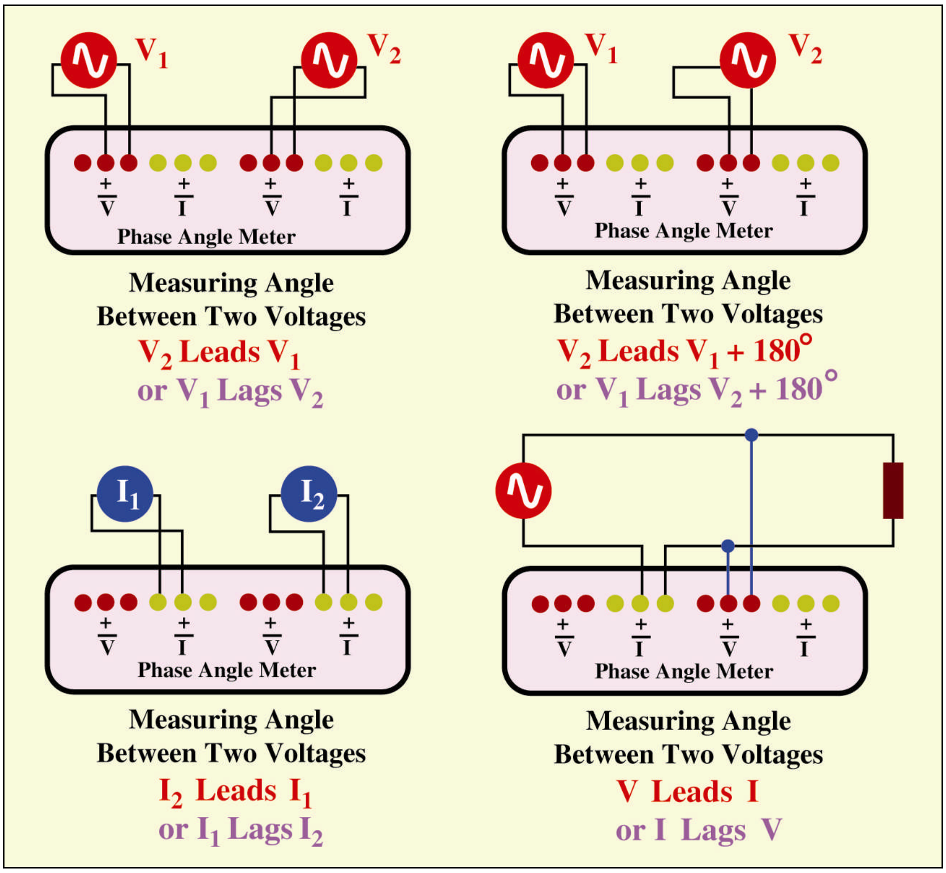


Fig. 5-1 Typical Phase Angle Meter Connections

TASK 1.3-6

FREQUENCY METER

OBJECTIVES

Upon completion of this task, the trainees will be able to:

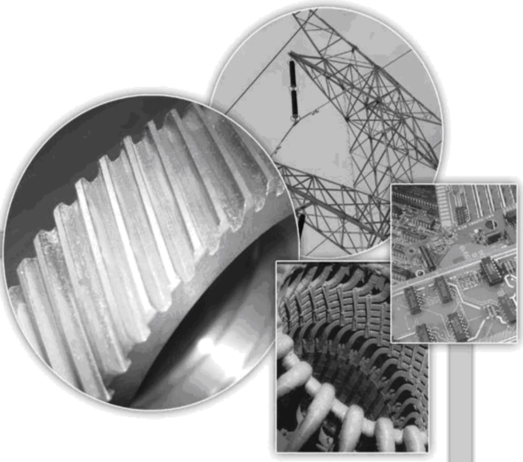
- Measure the Frequency using Frequency Counter.

EQUIPMENT AND MATERIALS

- 1 - Frequency Counter (Model SM - 2420)
- 1 - Function generator (Heathkit)

PROCEDURE

1. Prepare the counter to measure frequency.
2. Connect the function generator to the frequency counter.
3. Adjust the generator to obtain certain frequency and watch the counter.



LESSON 1.4

OSCILLOSCOPE

LESSON NO. 1.4
OSCILLOSCOPE

OVERVIEW

In this lesson, the trainees are familiarized with oscilloscope fundamentals and its applications in AC/DC measurements.

OBJECTIVES

Upon completion of this lesson, the trainees will be able to:

- Identify the oscilloscope controls.
- State the components of cathode ray tube.
- Use the oscilloscope properly while making AC/DC measurements.

Task 1.4-1: Oscilloscope Measurements

INTRODUCTION

A wide variety of instruments are used in electronics to measure the amplitude and frequency of AC signals. The oscilloscope (Fig.1.4-1) is one of these instruments. It not only measures amplitude and frequency but in addition, displays the shapes (waveforms) of different signals, simultaneously.

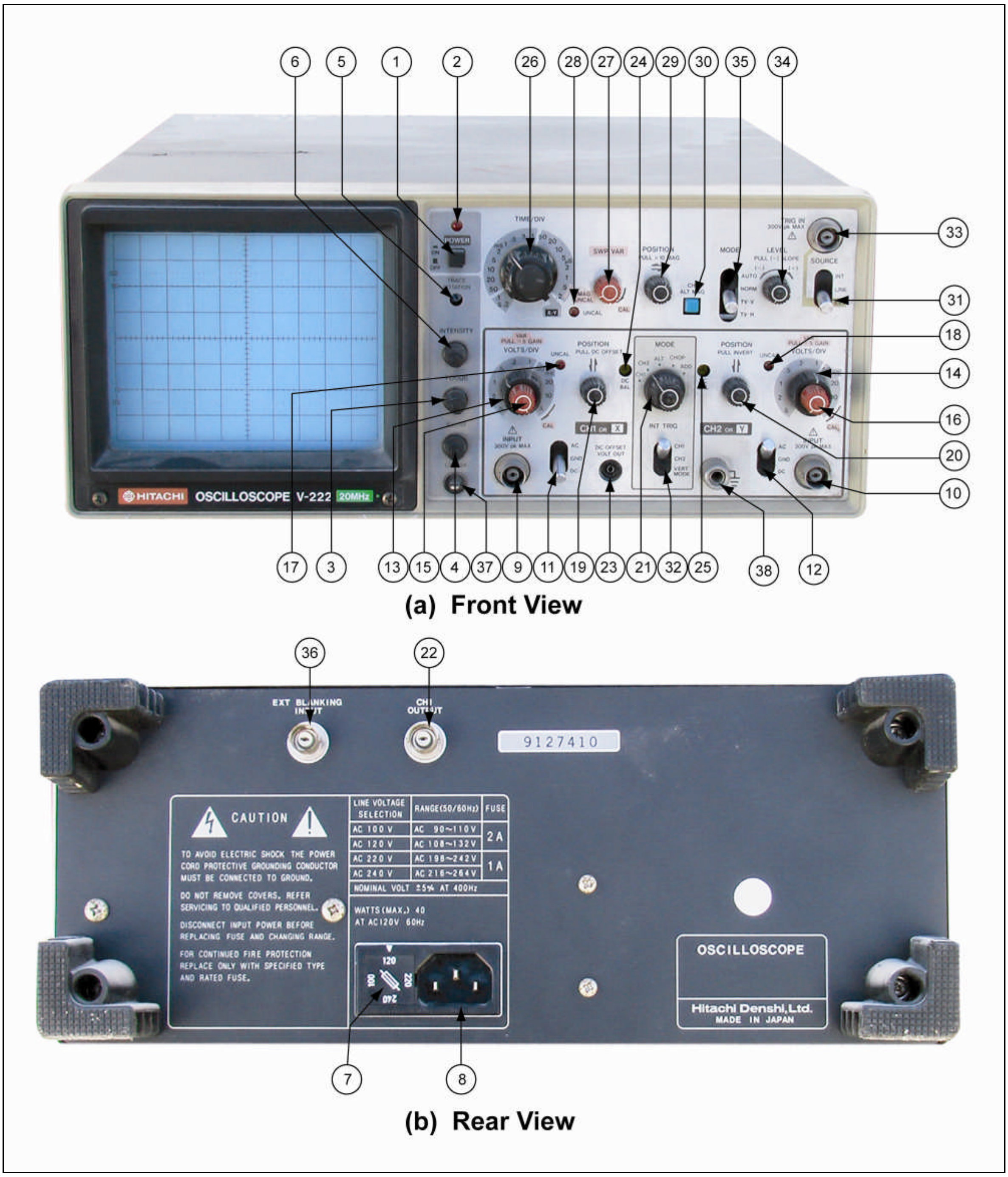


Fig.1.4-1 Oscilloscope (Hitachi V-222)

The principal components of the oscilloscope are a Cathode-Ray Tube (CRT), horizontal deflection circuit, vertical deflection circuit and high and low voltage power supplies.

CATHODE-RAY TUBE (CRT)

The oscilloscope is built around the CRT, which is the device that displays the waveforms on the front screen. The CRT is a vacuum tube device containing an electron gun that emits a narrow, focused beam of electrons. A phosphorescent coating on the face of the tube forms the screen. The beam is electronically focused and accelerated so that its strikes the screen, causing light to be emitted at the point of impact.

Fig.1.4-2 shows the basic construction of a CRT. The electron gun assembly contains a heater, cathode, control grid and accelerating and focusing grids. The heater carries current that heats the cathode. The heated cathode emits electrons. The amount of voltage on the control grid determines the flow of electrons and thus the intensity of the beam. The electrons are accelerated by the accelerating grid and are focused by the focusing grid into a narrow beam that converges at the screen. The beam is further accelerated to a high speed after it leaves the electron gun by a high voltage on the anode surfaces of the CRT.

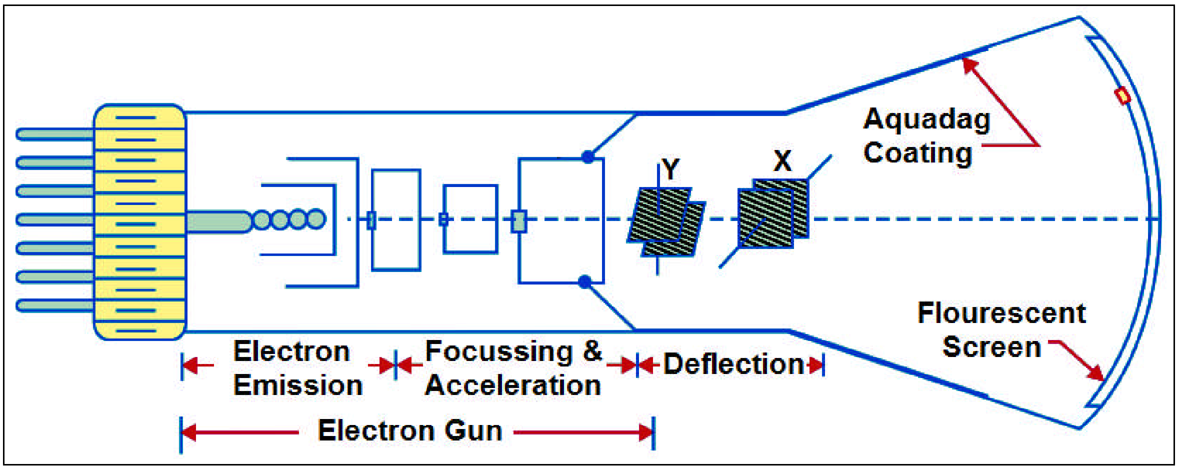


Fig.1.4-2 Basic Construction of CRT

The CRT screen is usually covered by a transparent overlay, called a graticule, which has a grid pattern graduated in centimeters. Each centimeter represents one division. The two axes (X and Y) of the graticule are used with the horizontal and vertical deflection circuits to measure time and amplitude directly from the displayed waveform.

BEAM DEFLECTION

The purpose of the deflection plates in the CRT is to produce a "bending" or deflection of the electron beam. This deflection allows the position of the point of impact on the screen to be varied. As mentioned before, there are two sets of deflection plates: one set for vertical deflection and the other set for horizontal deflection.

Fig.1.4-3 shows a front view of the CRT's deflection plates. One plate from each set normally is grounded as shown. If there is no voltage on the other plates, as in Fig. 4-3(a), the beam is not deflected and hits the center of the screen if a positive voltage is on the vertical plate, the beam is attracted upward, as indicated in Part (b) of the Fig. Remember that opposite charges attract. If a negative voltage is applied, the beam is deflected downward because like charges repel, as shown in Part (c).

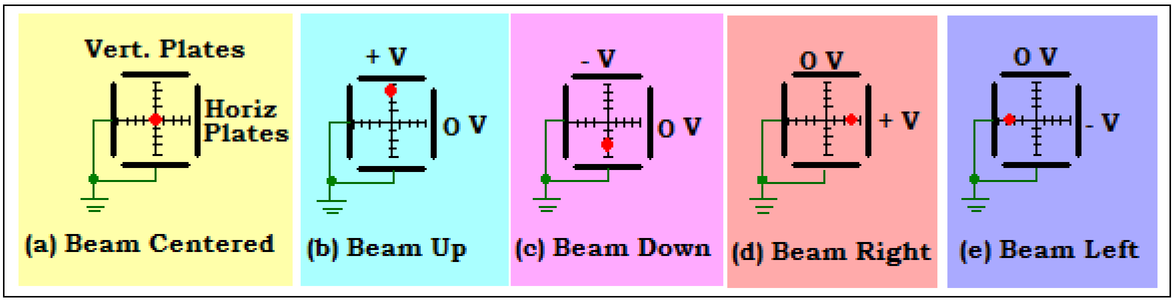


Fig.1.4-3 Deflection of Electron Beam in CRT

Likewise, a positive or a negative voltage on the horizontal plate deflects the beam right or left, respectively, as shown in Fig.4-3(d) and (e). The amount of deflection is proportional to the magnitude of the voltage on the plates.

SWEEPING BEAM HORIZONTALLY

In normal oscilloscope operation, the beam is horizontally deflected from left to right across the screen at a certain rate. This sweeping action produces a horizontal line or trace across the screen (Fig.1.4-4).

The rate at which the beam is swept across the screen establishes a time base. The scope screen is divided into horizontal and vertical divisions (Fig.1.4-4). For a given time base, each horizontal division represents a fixed interval of time. For example, if the beam takes 1 second for a full left-to-right sweep, then each division represents 0.1 second. All scopes have provisions for selecting various sweep rates, which will be discussed later.

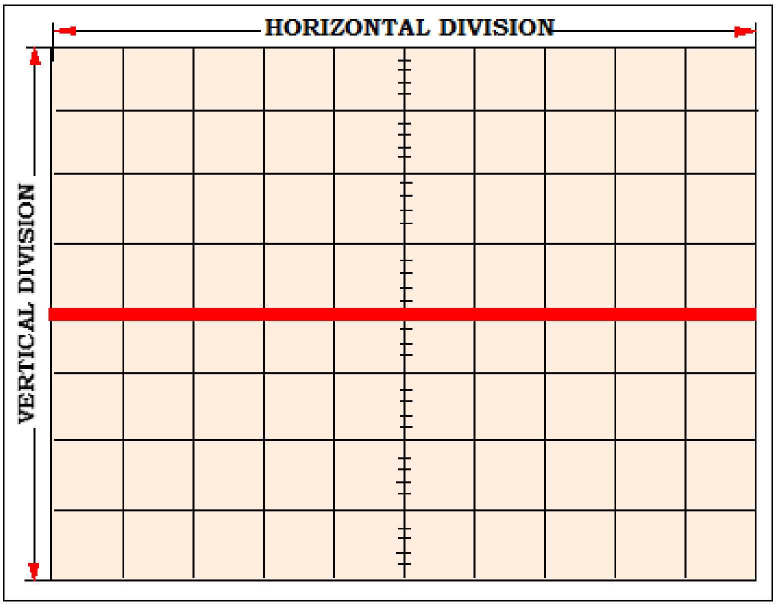


Fig.1.4-4 Scope Screen with Horizontal Trace (8 cm x 10 cm)

OSCILLOSCOPE CONTROLS

Regardless of their complexity, however, all scopes have certain operational features in common. In this section, we examine the most common front panel controls. Each control and its basic function are described. Fig. 1.4-1 shows a representative front panel of an oscilloscope.

SCREEN

In the left portion of Fig.1.4-1 is the CRT screen. There are 8 vertical divisions and 10 horizontal divisions indicated with grid lines or graticule. A standard screen size is 8 cm x 10 cm.

POWER SWITCH AND LIGHT (1)

This switch (1) turns the power to the scope on and off. The light indicates when the power is on. The oscilloscope in the lab can be operated from a 100 V/120 V or 220 V/240 V nominal line voltage source. The line voltage selector (7) is shown in Fig. 4-1. Power lamp (2) goes on in red when the power supply is in ON state.

FOCUS CONTROL (3)

After obtaining an appropriate brightness by operating INTENSITY, adjust FOCUS until the horizontal beam is clear and bright.

SCALE ILLUM CONTROL (4)

With this control you can adjust graticule illumination. It is useful to illuminate the graticule when viewing in a dark area, photographing.

TRACE ROTATION CONTROL (5)

This control is used to align the trace of CRT with the horizontal graticule.

INTENSITY CONTROL (6)

With this control brightness is increased or decreased by rotating Intensity Control clockwise or counter-clockwise, respectively.

POWER SOURCE SELECT SWITCH (7)

This control is used to select the power sources.

AC INLET (8)

This is inlet for detachable AC power cord to be plugged in.

CONTROLS OF VERTICAL DEFLECTION SYSTEM

CH1 INPUT CONNECTOR (9)

This is BNC connector for vertical axis input. The signal input to this terminal becomes the X-axis signal when the instrument is used as an X-Y oscilloscope.

CH2 INPUT CONNECTOR (10)

This is the same as CHI, but when the instrument is used as an X-Y oscilloscope, the signal input to this terminal becomes the Y-axis signal.

INPUT COUPLING SWITCHES (AC-GND-DC) (11)/ (12)

These switches are used to select the coupling system between the input signal and vertical axis amplifier.

AC: At this setting the signal is connected through a capacitor. The DC component of the input signal is cut off and only the AC component is displayed.

GND: At this setting the input to the vertical axis amplifier is grounded.

DC: At this setting the input signal is directly connected to the vertical axis amplifier and displayed unchanged, including the DC component.

VOLTS/DIV SELECT SWITCHES (13)/ (14)

This is a vertical step attenuator/multiplier, which selects vertical deflection factor. Multiply the reading by 10 when the 10:1 probe is used in combination with the instrument.

VAR / PULL × 5 GAIN CONTROLS (15) (16)

This is a fine tuning variable control used to vary the vertical deflection sensitivity continuously. Attenuation of less than 1/2.5 is obtained when this control is rotated in the reverse direction of the arrow to the full.

This control is used when comparing waveforms or when measuring the rise time of a square wave in 2-channel observation. Normally this control is left rotated in the direction of the arrow to the full. When the knob is at PULL position (pulled up state), the gain of the vertical axis is magnified 5 times and the maximum sensitivity becomes 1 mV/DIV.

POSITION / PULL INVERT CONTROL (20)

The same as $\mathbf{CH_1}$, but when the knob is at **PULL** position (pulled up state), this is used to inverse the polarity of the input signal applied to $\mathbf{CH_2}$. This control is conveniently used to compare two waveforms having different polarities or in the observation of the waveform of the difference signal ($\mathbf{CH_1}$) **-** ($\mathbf{CH_2}$) between $\mathbf{CH_1}$ and $\mathbf{CH_2}$ using ADD.

MODE SELECT SWITCH (21)

This switch is used to select the operation mode of the vertical deflection system.

CH_1: Only the signal that has been applied to **CH_1** appears on the screen.

CH_2: Only the signal that has been applied to **CH_2** appears on the screen.

ALT: Signals applied respectively to **CH_1** and **CH_2** appear on the screen alternatively at each sweep. This setting is used when the sweep time is short in 2-channel observation.

Chop: At this setting the input signals applied respectively to **CH_1** and **CH_2** are switched at about 250 kHz independent of the sweep and at the same time appear on the screen. This setting is used when the sweep time is long in 2-channel observation.

ADD: The algebraic sum of the input signals applied respectively to **CH_1** and **CH_2** appears on the screen.

CH1 OUTPUT CONNECTOR (22)

This is output connector providing a sample of the signal applied to the CH1 connector.

DC OFFSET/VOLT OUT CONNECTOR (23)

This is the output connector to readout the voltage measurement with a digital or analog multimeter, when the instrument is set to the DC OFFSET mode. (Except: ×5 GAIN, out of CAL)

DC/BAL ADJUSTMENT CONTROLS (24)/ (25)

These are used for the ATT balance adjustment.

CONTROLS OF HORIZONTAL DEFLECTION SYSTEM

TIME/DIV SELECT SWITCH (26)

Sweep time ranges are 19 steps from 0.2 μ s/div - 0.2 s/div.

X-Y: This position is used when using the instrument as an X-Y oscilloscope the X (horizontal) signal is connected to the input of CH1; the Y (vertical) signal is applied to the input of CH2 and has a deflection range from less than one millivolt to 5 volts/div at a reduced bandwidth of 500 kHz.

SWP VARIABLE CONTROL (27):

This control works as CAL and the sweep time is calibrated to the value indicated by TIME/DIV.

TIME DIV Sweep can be varied continuously when shaft is out of **CAL** position. Then the control is rotated in the direction of arrow to the full, the CAL state is produced and the sweep time is calibrated to the value indicated by TIME/DIV. Counterclockwise rotation to the full delays the sweep by 2.5 times or more.

SWEEP UNCAL LAMP (28)

Lights when SWP Var is out of CAL detect position.

POSITION/PULL × 10 MAG CONTROL (29)

As shown in Fig. 4-5, this control knob is used to move the trace in horizontal directions. It is indispensable in the measurement of the time of waveform. Bright line is moved toward right when the knob is rotated clockwise and toward left with counterclockwise rotation. Sweep is magnified 10 times by pulling out knob of

POSITION. In this case the sweep times is 1/10 of the value indicated by TIME/DIV. Bring the position of the waveform desired to be magnified observed to the outer of the scale by operating - POSITION of the horizontal axis. Next, switch 10 MAG switch to PULL pulled out state. Then the waveform placed at the center is magnified in right and left directions. The sweep time in this case is 10 times the sweep speed obtained by TIME/DIV, in other words, the reading is 1/10 of the sweep time indicated.

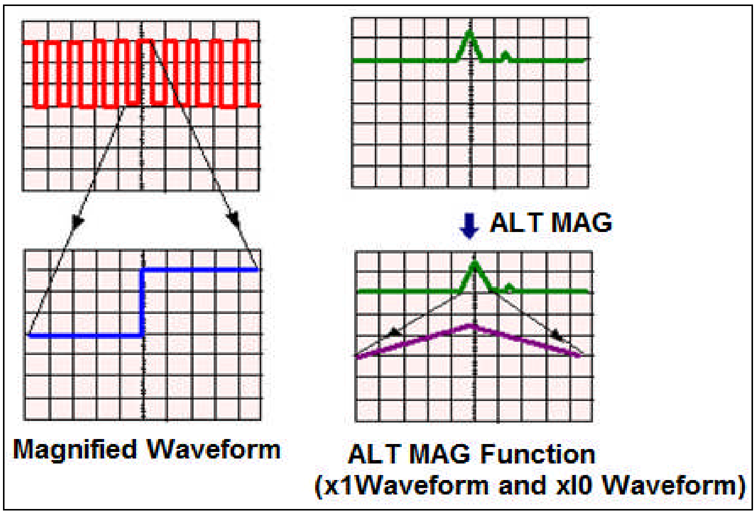


Fig. 1.4-5 Times 10 Multiplier

CH1 ALT MAG SWITCH (30)

CHI input signal is displayed alternately by each single sweep of ×1 of (NORM) and ×10 (MAG).

- Set the wished portion of the waveform to the screen center for magnification.
- The ×10 waveform appears 3 divisions below the ×1 waveform.

SYNCHRONIZATION SYSTEM

SOURCE SELECT SWITCH (31)

This switch is used to select the triggering signal source sweep.

INT: The input signal applied to **CH_1** or **CH_2** becomes the triggering signal.

LINE: This setting is used when observing a signal triggering with power supply line frequency.

EXT: External triggering signal applied to TRIG INPUT becomes the triggering signal. This setting is used when triggering with a special independent of the vertical axis signal.

INT TRIG SELECT SWITCH (32)

This switch is used to select the internal triggering signal source sweep.

CH_1: The input signal applied to **CH_I** becomes the triggering signal.

CH_2: The input signal applied to **CH_2** becomes the triggering signal.

VERT MODE: For observing two waveforms, the sync signal changes alternately corresponding to the signals on CHI and CH2 to trigger the signal.

TRIG INPUT CONNECTOR (33)

This trigger input connector is used for external triggering signal of sweep.

TRIG LEVEL CONTROL (34)

This control knob is used to decide at which portion of the waveform the sweep to be started by setting trigger level. This knob is also enabled to switch SLOPE.

Depressed position (normal state) is for (+) SLOPE and PULL position (state in which the knob is protruding) is for (-) SLOPE.

TRIG MODE SELECT SWITCH (35)

AUTO: The instrument is brought into automatically triggering sweep in which sweep is always conducted. In the presence of triggered signal, normal triggered sweep is obtained and the waveform stands still. In the case of no signal or out of triggering, sweep line will appear automatically. This setting is convenient in usual cases.

NORM: Triggered sweep is obtained and sweep is conducted only when triggering is affected. No sweep line will appear in the case of no signal or out of synchronization. Use this MODE when affecting synchronization to a very low frequency signal (25 Hz or less).

TV(V): This setting is used when observing the entire vertical picture of television signal.

TV(H): This setting is used when observing the entire horizontal picture of television signal.

NOTE

Both TV V and TV H synchronize only when the synchronizing signal is negative.

MISCELLANEOUS

EXT BLANKING CONNECTOR (36)

This Input connector is for brightness modulation. It is of the DC coupling. The brightness is reduced with a positive signal and increased with a negative signal.

CAL 0.5V TIP (37)

This is an output connector with calibration square wave of about I kHz and 0.5V. It has a tip terminal and is used to calibrate the probe combination.

OSCILLOSCOPE BLOCK DIAGRAM

The block diagram of a Classical Oscilloscope is presented in Fig. 1.4-6. Recently, the cathode ray tube is often substituted by the liquid crystal display LCD.

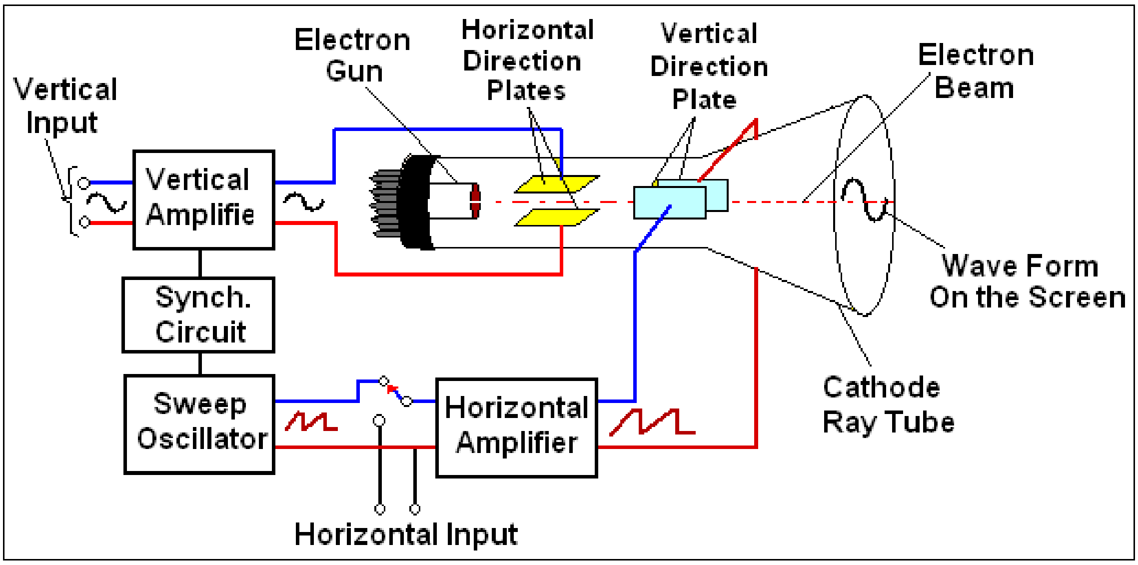


Fig. 1.4-6 the Block Diagram of a Classical Oscilloscope

SUMMARY

- An Oscilloscope visually displays instantaneous (real-time) and peak values of voltage.
- An Oscilloscope Graticule (grid, mask, grating) is a transparent scale with vertical and horizontal markings that allow time and amplitude to be measured directly.
- An Oscilloscope can be used in place of a Voltmeter to measure AC/DC voltages.

- The principal components of the Oscilloscope are a Cathode Ray Tube (CRT), horizontal deflection circuit, vertical deflection circuit and high and low voltage power supplies.
- The CRT contains an electron gun and sets of horizontal and vertical deflection plates.
- The purpose of the deflection plates in the CRT is to produce a "bending" or deflection of the Electron Beam.
- The Electron Gun produces and focuses and electron beam on a phosphorescent coating on the inside face of the tube, causing a visible spot to appear on the face of the tube when viewed from the front.
- When voltages are applied to the Deflection Plates from the horizontal and vertical deflection circuits, the Electron Beam and thus the bright spot, is made to move by the combined effect of the two deflection voltages and the trace appears as a visible pattern on the screen.
- The amount of deflection is proportional to the amount of voltage on the plates.

GLOSSARY

Oscilloscope	Using in electronics to measure the amplitude and frequency of AC signals
Cathode ray tube (CRT)	A device that displays the waveforms on the front screen
Liquid crystal display(LCD)	An electronic visual display in which the application of an electric current to a liquid crystal layer makes it opaque
Time Base	Rate at which the beam is swept across the screen, horizontally

REVIEW EXERCISE

Choose the correct answer:

1. An oscilloscope visually displays _______________ (real-time) and __________ values of voltage.

   a.- root mean square   b.- average

   c.- peak to peak   d.- instantaneous

2. The electron gun produces and focuses and electron beam on a phosphorescent coating on the inside face of the ________.

   a.- vertical direction plates   b.- tube

   c.- amplifier   d.- horizontal direction plates

3. A standard screen size on an Oscilloscope is ___________.

   a.- 4cm × 5cm   b.- 12cm × 15cm

   c.- 16cm × 20cm   d.- 8cm × 10cm

Complete by filling in blanks

4. Basically, the **CRT** contains an electron gun and sets of __________ and __________ deflection plates.

5. **Check True for the correct sentence and False for the wrong sentence:**

	T	**F**
a. - An oscilloscope can be used in place of a voltmeter to measure DC or AC voltages		
b. - The Trace Rotation Control on an Oscilloscope is used to align the trace of CRT with the horizontal Graticule scale		
c. - In **CHOP** mode on an Oscilloscope, the signals applied respectively to **CH1** and **CH2** appear on the screen alternatively at each sweep.		

6. Identify all the functional blocks in Fig. 1.4-7 for the block diagram of an Oscilloscope.

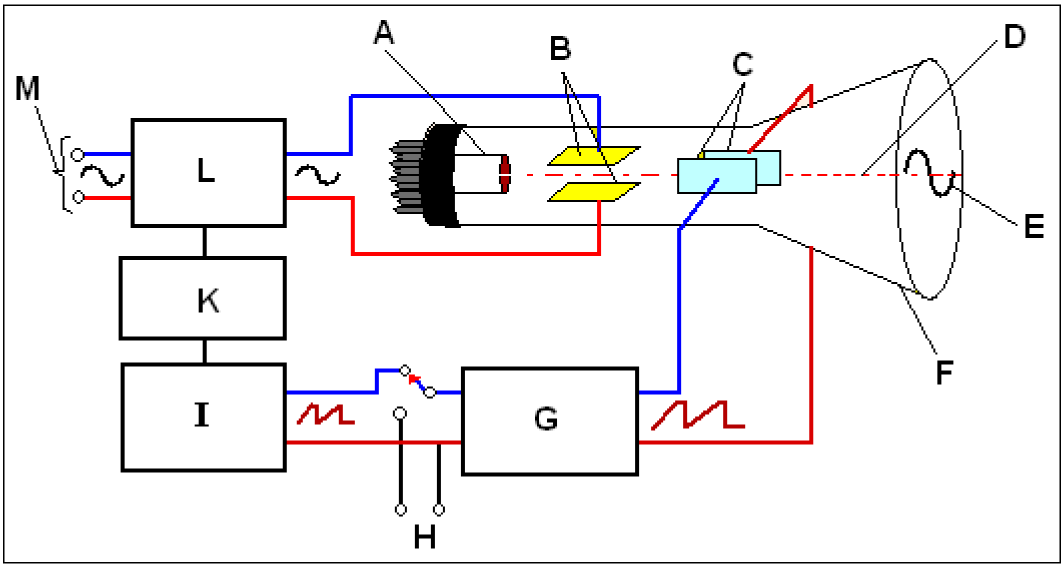


Fig. 1.4-7 Oscilloscope Block Diagram

TASK 1.4-1

OSCILLOSCOPE MEASUREMENTS

OBJECTIVES

Upon completion of this task, the trainees will be able to:

- Identify the controls of an Oscilloscope and display the calibration voltage.
- Measure AC/DC voltages.
- Measure Period and Frequency of an AC signal.

EQUIPMENT

- 1 - ET-3100 Electronic Design Trainer
- 1 - Oscilloscope
- 1 - Scope lead, 1:1
- 1 - Scope lead, 10:1

PROCEDURE

1. Identify the Oscilloscope Controls to the Instructor.
2. Before turning ON the power switch, ensure that the power supply voltage is within the range of the wall plug.

3. Insert the plug of the power cord on the rear panel into the power supply wall socket and set the controls as follows:

CONTROL	SETTING
POWER	OFF
INTEN	Counterclockwise to full position
FOCUS	Midrange
AC-GND-DC	GND
POSITION	Midrange (knob in the depressed position)
V. MODE	CH1
TRIG	AUTO
TRIG SOURCE	INT
INT TRIG	CH1
TIME/DIV	0.5ms/DIV
POSITION	Midrange

4. Set the levers of the switches to the upper side.
5. After finishing all the settings mentioned above, turn ON the POWER and, 15 second later, rotate the INTEN knob clockwise, so that the sweep bright line appears on the screen. For the observation to be started immediately, set the FOCUS control at a point where the bright line is sharpest.
6. If the instrument is not used with the power supply turned ON, rotate the **INTENSITY** control counterclockwise **(CCW)** to reduce the brightness and also blur the **FOCUS**.

NOTE

For usual observation, leave the following non-calibrating function section set to "CAL" position.

FUNCTION	DESCRIPTION
VARIABLE	Rotate in the direction of arrow. In this case the VOLTS/DIV is calibrated to its indicating value.
SWP VAR	Leave the knob in depressed state. In this case the TIME/DIV is calibrated to its indicating value.

7. Align the bright line with the horizontal scale line at the center of the screen by operating **CH1 POSITION** control. In some cases the bright line may be oblique to the scale slightly by the effect of earth's magnetism. In this case, bring the bright line until it lies on the horizontal scale line at the center of the screen by properly adjusting the semi-fixed variable resistor **TRACE ROTATION** on the front panel.
8. To check calibration voltage (15VAC on ET-3100), connect the probe to CH1 or CH2.
9. Make the following settings when using CH1.

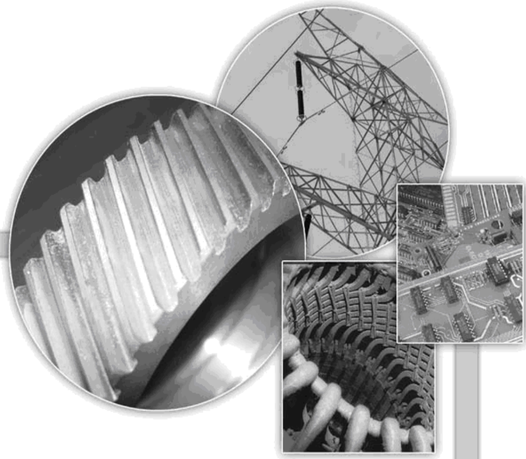
MODE Switch of Vertical defection system	CH1
MODE Switch of TRIG	AUTO
TRIG SOURCE	INT
INT TRIG	CHI

10. The wave should appear on the scope screen (peak-peak) value.
11. Rotate the **LEVEL** control slowly **CW** or **CCW** until the signal stabilizes.
    Set the **VOLTS/DIV** control on CH1 to 1V/DIV.
12. Measure the peak-to-peak value of the waveform using **VOLTS/DIV** setting.

NOTE

Always measure the AC signals using the calibrated time base of the Oscilloscope.

13. To measure DC voltage, set input coupling to GND and adjust the zero level properly.
14 Set **VOLTS/DIV** control to 50mV/DIV to measure DC value, using DC from the ET-3100 Trainer.
15 Set AC-GND-DC select switch to DC. The bright line shifts by the amount of DC voltage of the signal and you can obtain the value by multiplying the shifted width by the indicated value of VOLTS/DIV.
16. Calculate the DC voltage indicated by the shifted trace from zero reference on the Oscilloscope display. **DC voltage = _________V**
17. Setup the AF Generator on the ET-3100 Trainer to the sine wave mode and connect the Oscilloscope to the generator output. Adjust the output voltage to a value that produces a convenient peak-to-peak deflection on the Oscilloscope.
18. Set AF generator to a frequency of 1000Hz.
19. Set **TRIG** source to **INT**, **TRIG** to **AUTO** and AC-GND-DC to AC positions.
20. Set the **TIME/DIV** to an appropriate setting that produces a minimum of two complete cycles on the Oscilloscope and record the Time Base switch setting.
    TIME/DIV = _________
21. Rotate the vertical **POSITION** control to align the zero axis of the sine wave with the scope graticule X-axis.
22. Slowly rotate the **LEVEL** control until the beginning of the first sine wave coincides with the scope graticule X-axis.
23. Rotate the Horizontal Position ↔control until the beginning of the first cycle coincides with the first vertical line on the Graticule.
24. Measure the horizontal width in divisions and fractions of the first cycle of complete sine wave using the Oscilloscope graticule.
    Horizontal width = _______DIV
25. Calculate the time period **(T)** of one complete cycle of the input voltage by multiplying the **TIME/DIV** setting recorded before by the horizontal width.
    Time period, T = TIME/DIV × No. of DIV = _________ms
26. Calculate the frequency of the input signal voltage: **f = 1/T Hz**



LESSON 1.5

MAGNETISMAND ELECTROMAGNETIC INDUCTION

LESSON 1.5

MAGNETISM AND ELECTROMAGNETIC INDUCTION

OVERVIEW

This lesson explains the fundamental properties of magnetism in magnetic materials and devices and concludes with application of magnetic induction.

OBJECTIVES

Upon completion of this lesson, the trainees will be able to:

- Define the magnetic parameters (magnetic field, field lines, magnetic flux (ϕ) flux density (β), permeability of magnetic materials and magnetic lines of force).
- Describe the characteristics of electromagnetism (field intensity (H), field produced by two parallel conductors, electromagnet, solenoid, field produced by solenoid, saturation, magnetic hysteresis, hysteresis loop, and relay).

Task 1.5-1: Electromagnetic Induction

Task 1.5-2: Relay Application

INTRODUCTION

Magnetic phenomena are observed in nature as well as in industrial and scientific applications. The magnetic properties of the earth permit the use of the compass and other more sophisticated instruments for navigational purposes. Many other uses of magnetism can be found in everyday life. Electromagnetic relays are devices that are magnetic in nature therefore, any study of protective relaying must include a study of magnetic forces. This lesson will provide the background for an understanding of magnetism.

MAGNETIC PARAMETERS

MAGNETIC FIELD

The magnetic field of a magnet has an effect on the space surrounding it. This effect is represented by magnetic lines drawn from North Pole to South Pole and known as the magnetic field or flux of the magnet (Fig. 1.5-1). A strong magnetic field is represented by close magnetic lines.

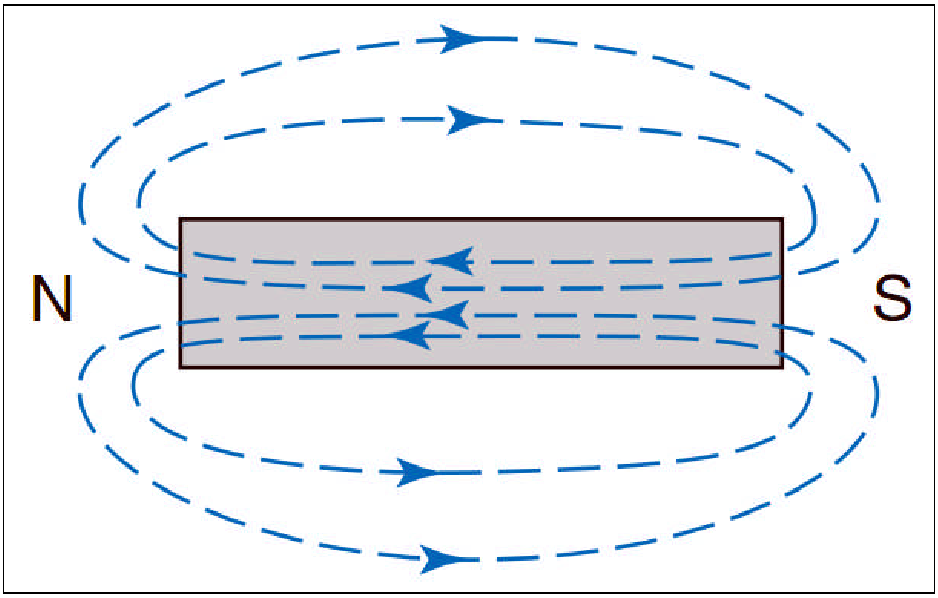


Fig. 1.5-1 Magnetic Field

FIELD LINES

Magnetic field lines (Fig. 1.5-1) begin at a magnet's North Pole and end on the South Pole. The field lines are close together where the field is strong and get farther apart as the field gets weaker. As you can see in the Fig.1.5-1, the magnetic field is strongest close to the magnetic poles and grows weaker farther from the poles.

Fig. 1.5-2(a) illustrates unlike magnetic poles, **N-S**, attract each other (**attraction)**. The magnetic field lines are directed out of the **N** pole and in the **S** pole.

Fig. 1.5-2(b) illustrates like magnetic poles, either **N-N** or **S-S**, repel each other. This is shown by the pattern of field lines when like poles are placed close together (**repulsion**).

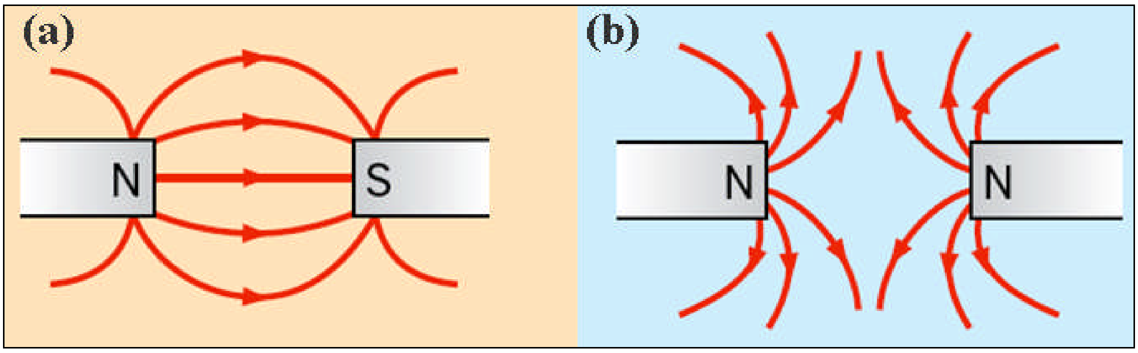


Fig. 1.5-2 Magnetic Field Lines Attraction and Repulsion

MAGNETIC FLUX ϕ

The entire group of magnetic field lines, which can be considered to flow outward from the north pole of a magnet, is called magnetic flux. Its symbol is the Greek letter phi **(ϕ)**. A strong magnetic field has more lines of force and more flux than a weak magnetic field.

The overall magnitude of a magnetic field is measured in units called **webers** (**Wb**). A smaller unit, the **maxwell** (**Mx**), is sometimes used if a magnetic field is weak. One

weber is equivalent to 100,000,000 (10^s) maxwells. Conversely, 1 Mx = 0.00000001 Wb = 10^{-8} Wb.

FLUX DENSITY B

Flux density is the number of magnetic **field lines per unit area** of a section perpendicular to the direction of flux represented by the symbol **B**.

$$\mathbf{B} = \frac{\mathbf{\Phi}}{\mathbf{A}}$$

TESLA AND GAUSS

If you have access to a permanent magnet or electromagnet, you might see its strength expressed in terms of **webers** or **maxwells**. But usually you'll hear units called **teslas** (**T**) or **gauss** (**G**). These units are expressions of the concentration, or intensity of the magnetic field within a certain cross section.

The flux density, or number of lines per square meter or per square centimeter, is a more useful expression for magnetic effects than the overall quantity of magnetism.

A flux density of 1 Tesla (1 T) is equal to 1 Weber per square meter (1 Wb/m^2). A flux density of 1 Gauss (1 G) is equal to 1 Maxwell per square centimeter (1 Mx/cm^2). It turns out that the Gauss is equal to 0.0001 Tesla (10^{-4} T). Conversely, the Tesla is equivalent to 10,000 Gauss (10^4 G).

EXAMPLE

The pole face of a magnet is 3 cm by 2 cm and it produces a flux of 30 μWb. Calculate the flux density at the pole face.

SOLUTION

$$B = \frac{\Phi}{A} = \frac{30X10^{-6}}{6X10^{-4}} = 50\ \text{mT}$$

MAGNETIC LINES OF FORCE

The magnetic lines of force have the following three major characteristics:

- Pass through all materials, both magnetic and nonmagnetic.
- Always enter or leave magnetic material at right angles to the surface.
- Tend to flow in paths of least opposition.

ELECTRIC CURRENT AND MAGNETISM

A CURRENT PRODUCES A MAGNETIC FIELD

When a current is passed through a wire (Fig.1.5-3) it creates a magnetic field around the wire, which is demonstrated by the deflection of a plotting compass. While the current is flowing the compass needle deflects but as soon as the current is switched off the compass needle returns to pointing north.

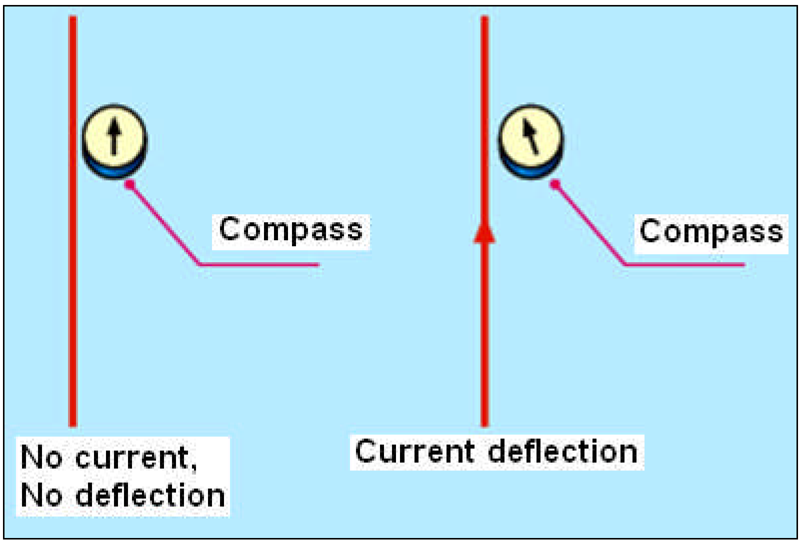


Fig. 1.5-3 A Current Produces a Magnetic Field

FIELD PATTERNS PRODUCED BY CURRENTS

The magnetic field around a wire carrying a current consists of a series of concentric circles. The direction of the field is determined by the direction of the current.

Conventionally, if a wire is represented is section, a current coming out of the page is represented by a dot (•) while a current passing into the paper is represented by across (+). The dot and cross represent the tip and tail of an arrow, respectively, (Fig. 1.5-4).

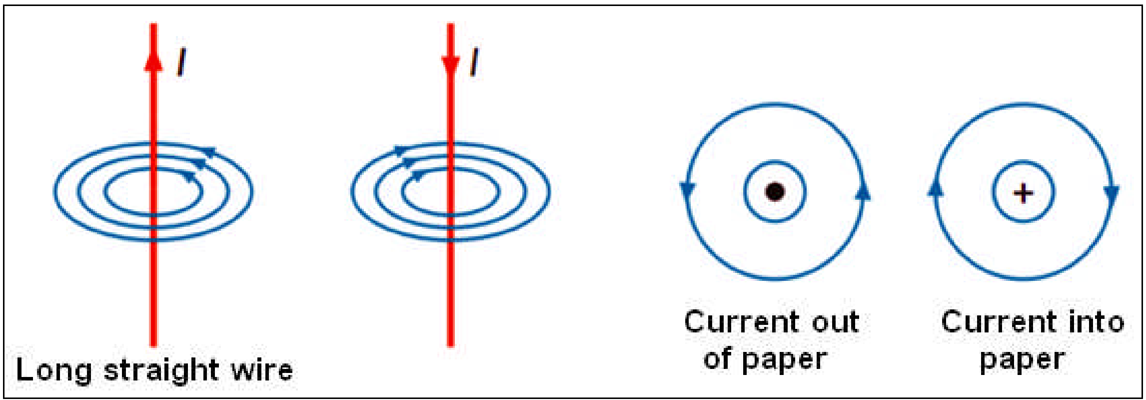


Fig. 1.5-4 the Magnetic Field around a Wire Carrying a Current

RIGHT HAND SCREW RULE

The direction of the magnetic field around a wire carrying a current can be predicted using the "right hand screw rule" (Fig. 1.5-5) If a right-handed screw moves forward in the direction of the conventional current then the direction of rotation of the screw gives the direction of the magnetic field lines.

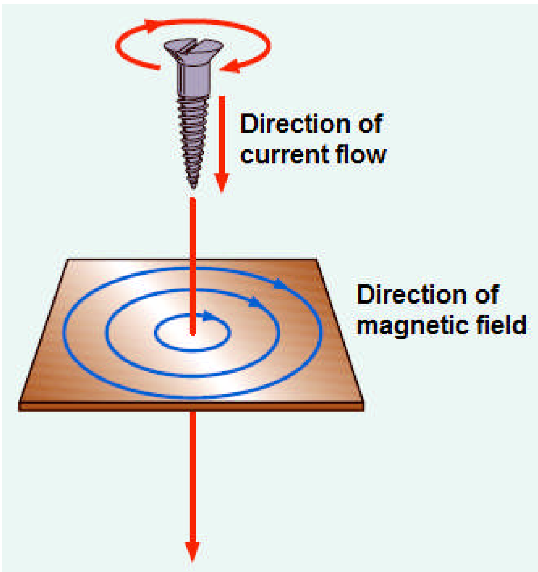


Fig. 1.5-5 Right Hand Screw Rule

FIELD PRODUCED BY TWO PARALLEL CONDUCTORS

When two parallel conductors (Fig. 1.5-6) are both carrying current, their magnetic fields will interact to produce a force of attraction or repulsion between them.

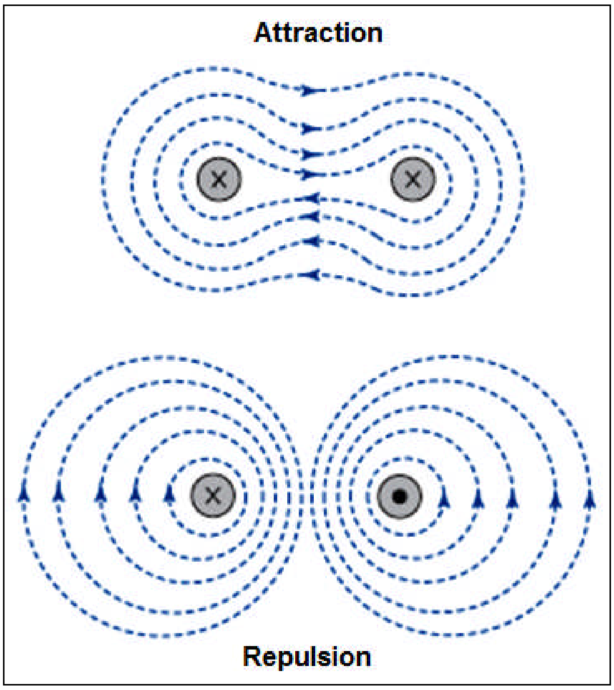


Fig. 1.5-6 Field Produced By Two Parallel Conductors

ELECTROMAGNETS

An electromagnet can be produced by simply feeding a current through a coil of wire that is wrapped around an iron bar. When the current is turned on, the iron bar becomes magnetized, and when the current is turned off. The magnetism is lost. In this manner a magnet can be constructed that may be turned on and off at will. This phenomenon has profound implications for electromechanical devices. Fig. 1.5-7 shows a simple electromagnet, power source, and field lines. Notice the field lines are similar to the lines of a common bar magnet.

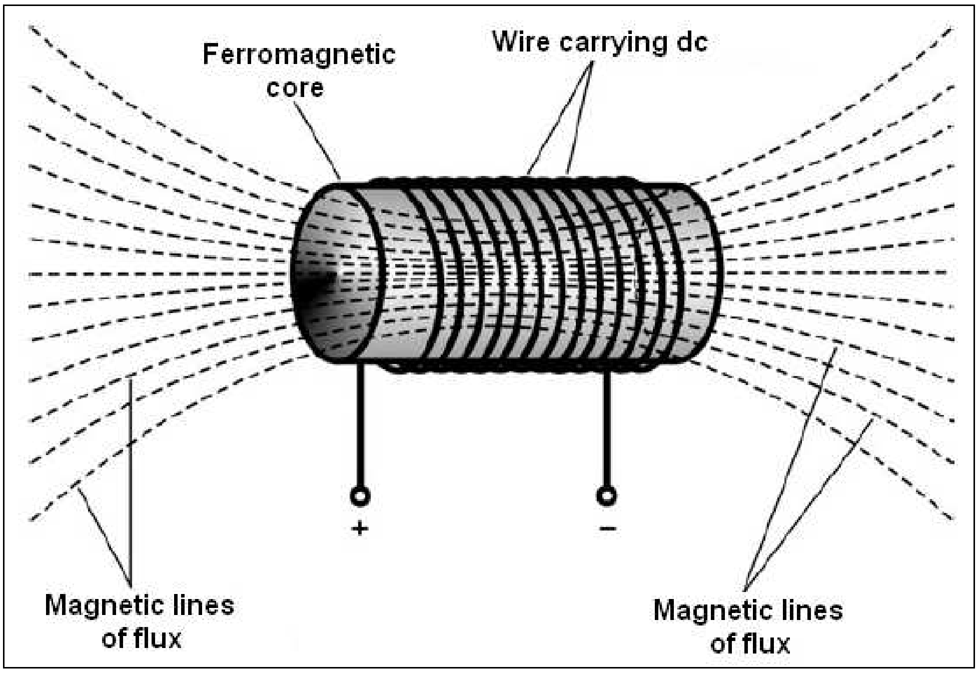


Fig. 1.5-7 the Principle of an Electromagnet

SOLENOID

The solenoid is a coil wound on iron core (Fig. 1.5-8) and it will appear as a magnetic field with a (**N**) pole at one end and a (**S**) pole at the other opposite end. Winding the coil around a soft iron core increases the flux density because the lines of magnetic flux concentrate on the magnetic material.

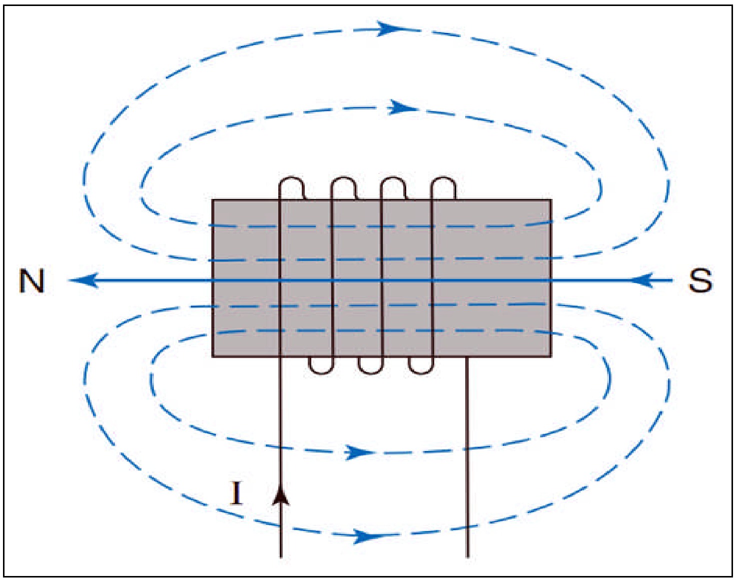


Fig. 1.5-8 an Iron-Cored Solenoid

The advantage of the electromagnet when compared with the permanent magnet is that the magnetism of the electromagnet can be switched on and off by a functional switch controlling the coil current. This effect is put to practical use in the **electrical relay** as used in a motor starter or alarm circuit. Fig. 1.5-9 shows the structure of the solenoid.

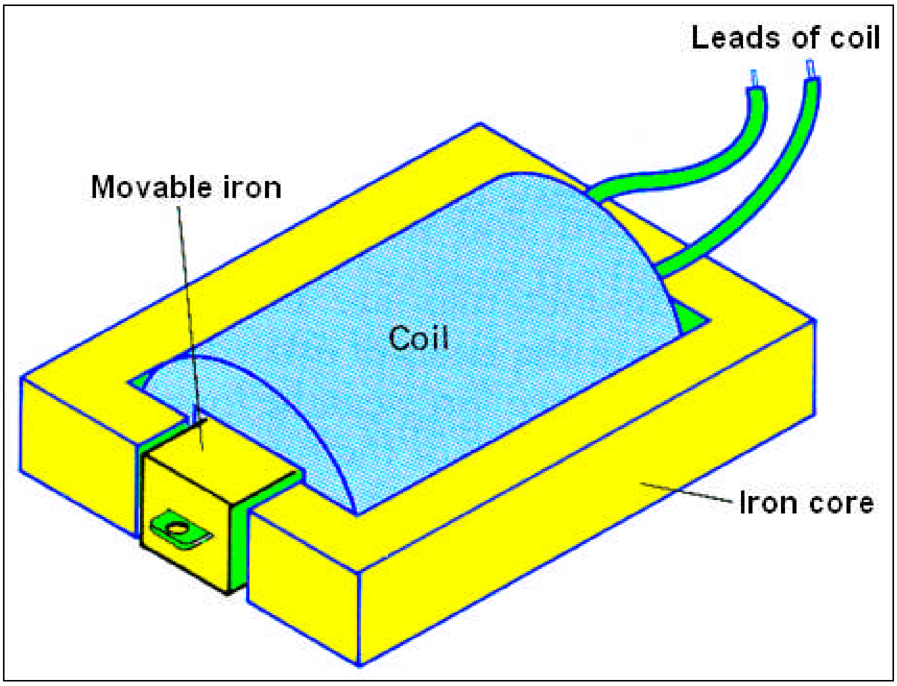


Fig. 1.5-9 Structure of Solenoid

MAGNETO MOTIVE FORCE

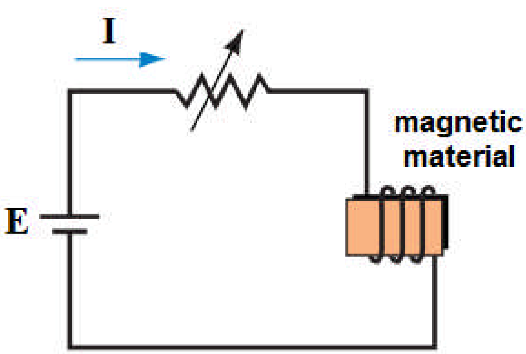
<table>
<tr>
<td>Magneto motive force (mmf) is the strength of a magnetic field in a coil of wire. This is dependent on how much current flows in the turns of coil (Fig. 1.5-10). the more current, the stronger the magnetic field; the more turns of wire, the more concentrated the lines of force.</td>
<td>

Fig. 1.5-10 The Magnetizing Circuit</td>
</tr>
</table>

The mathematical representation for Magneto motive force (mmf) is:

F_m (mmf) = N × I AT (Ampere-Turns)

Where: **F_m** = magneto motive force (mmf)

N = number of turns

PERMEABILITY

Permeability is a measure of the effectiveness of a material as a path for magnetic lines of force as compared with the effectiveness of air.

NOTE

Some materials such as iron have high permeability, others such as aluminum have medium permeability and still others such as silver and gold have low permeability.

Table 1.5-1 gives permeability values for some common materials.

Substance	Permeability (approx.)
Air, dry, at sea level	1
Alloys, ferromagnetic	3000-1,000,000
Aluminum	Slightly more than 1
Bismuth	Slightly less than 1
Cobalt	60-70
Iron, powdered and pressed	100-3000
Iron, solid, refined	3000-8000
Iron, solid, unrefined	60-100
Nickel	50-60
Silver	Slightly less than 1
Steel	300-600
Vacuum	1

Table 1.5-1 Permeability Values

FIELD INTENSITY (H)

The Ampere-Turns of mmf specifies the magnetizing force but the intensity of the magnetic field depends on how long the coil is. At any point in space, a specific value of Ampere-Turns for a long coil must produce less field intensity than a short coil that concentrates the same NI. Specifically the field intensity (H) is:

$$\mathbf{H} = \frac{\mathbf{N \times I\ (Ampere - Turn)}}{\boldsymbol{\ell}\ \mathbf{(meter)}} \quad (\mathbf{For\ solenoid})$$

Where: **N** = Turns (T) **I** = Current (A) ℓ = Length of core (m)

H = Field intensity at the center of air core (AT/m)

A good magnetic material with high relative permeability can concentrate flux and produce a large value of flux density, for a specified **H**. These factors are related by the formula:

$$\mathbf{B = \mu\ H} \qquad \text{or} \qquad \mathbf{\mu = \frac{B}{H}}$$

Where: **B** = Flux density (Tesla)

H = Field intensity (AT/m)

The factor **μ** is the absolute permeability, not referred to any other material, in units of **B/H**. The (**B-H**) curve in Fig. 1.5-11 is often used to show how much flux density **B** results from increasing the amount of field intensity **H**.

For magnetic materials, **saturation** is the state when the material cannot absorb a stronger magnetic field, such that an increase of magnetization force produces no change in magnetic flux density.

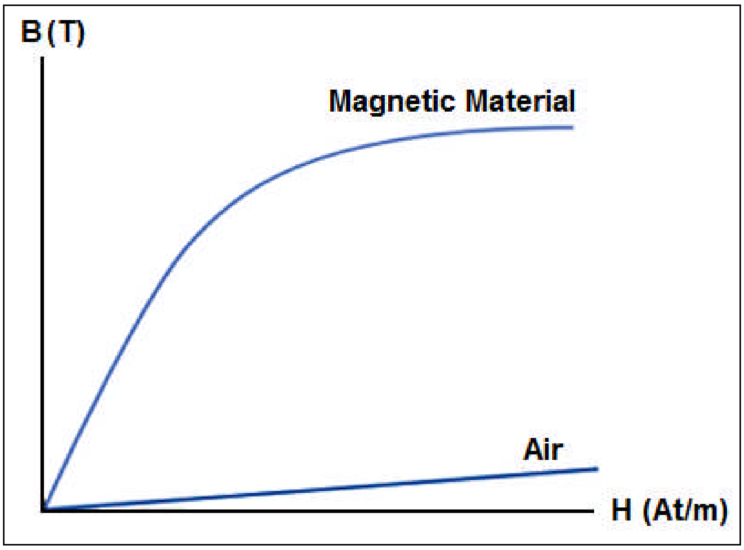


Fig. 1.5-11 B-H Magnetization Curve

HYSTERESIS

If you reduce the current in Fig. 1.5-10 to zero, you will find that the material still keeps some magnetism, called **residual magnetism** (Fig. 1.5-12, point **b**). If now you reverse the current, the flux reverses and the bottom part of the curve can be traced. By reversing the current again at **d**, the curve can be traced back to point **a**. The result is called a **hysteresis loop**.

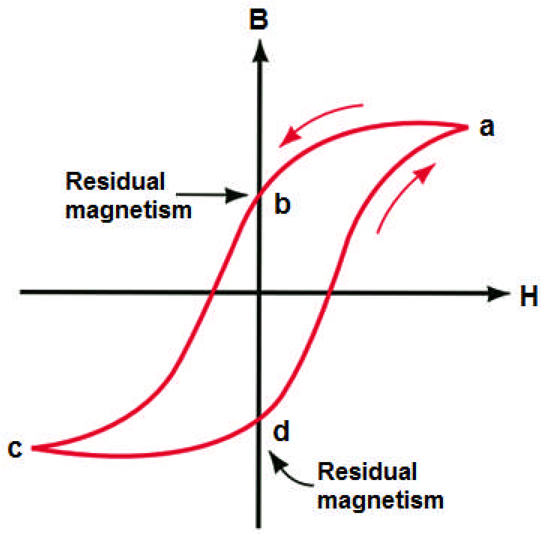


Fig. 1.5-12 Hysteresis Loop

RIGHT HAND GRIP RULE

The polarity of a solenoid can be predicted using the "right hand grip rule." If the right hand is placed over solenoid with fingers pointing in the same direction as the conventional current passing through each coil, the direction of the N pole of the

solenoid is given by the thumb (Fig. 1.5-13). If the direction of the current is reversed its polarity is also reversed.

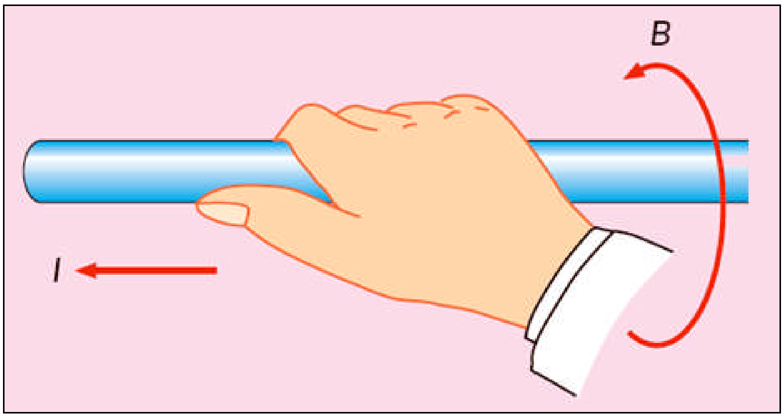


Fig. 1.5-13 Right hand grip rule

THE RELAY

A relay is essentially an electromagnetic device used to open or close a switch that controls another circuit. Fig. 1.5-14 shows a typical relay circuit when switch $\mathbf{S_1}$ is closed, the coil circuit is energized. The coil current gradually increases and produces a magnetic field. Eventually the magnetic field is sufficiently strong to pull the movable contact in the other circuit and close switch $\mathbf{S_2}$ that closes another circuit.

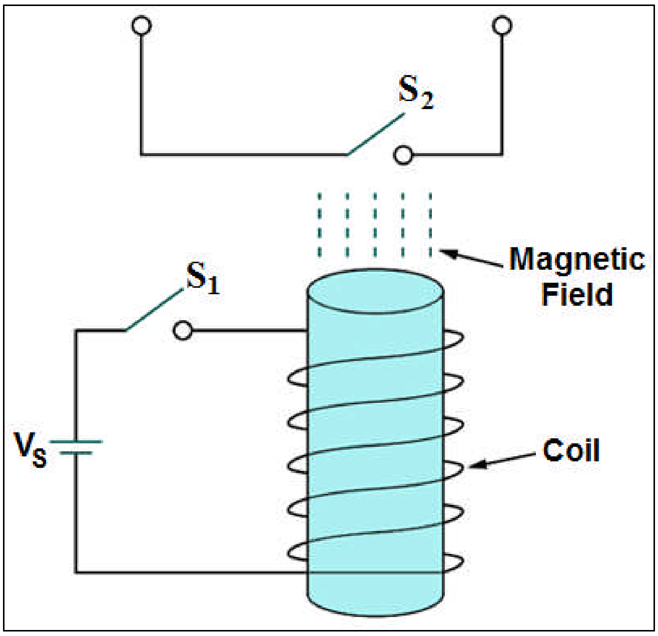


Fig. 1.5-14 Simple Relay Circuit

Fig. 1.5-15 shows how a relay is used in practice. When the switch is closed, the energized coil pulls the armature down. This closes the contacts and energizes the load. When the switch is opened, the spring pulls the contacts open again. Schemes like this use relatively small currents to control large loads. In addition, they permit remote control, as the relay and load may be a considerable distance from the actuating switch. Fig. 1.5-16 shows a simple electromagnetic relay

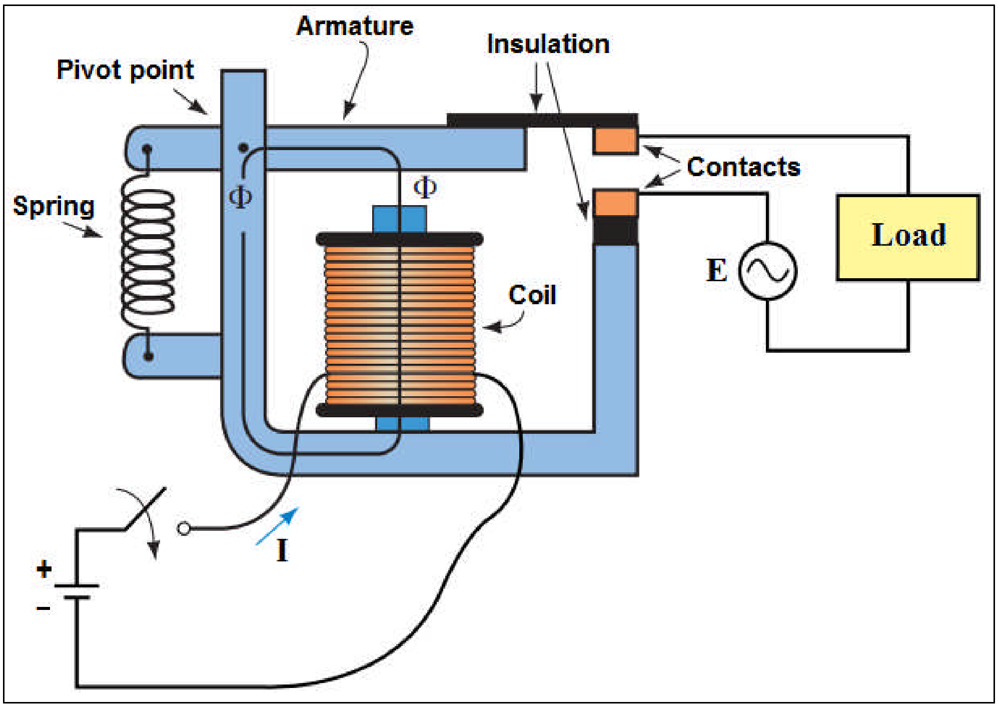


Fig. 1.5-15 Controlling a Load with a Relay

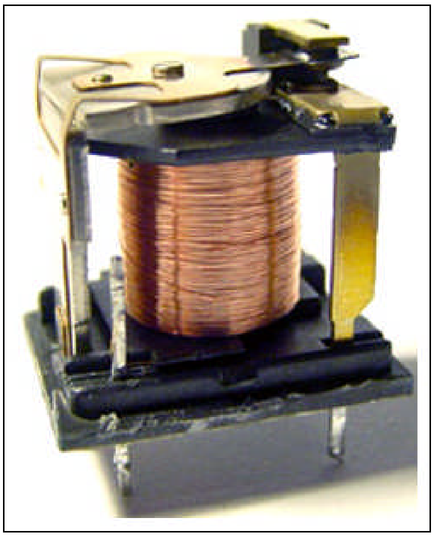


Fig. 1.5-16 Electromagnetic Relay

SUMMARY

- Magnetic phenomena are observed in nature as well as in industrial and scientific applications.
- Electromagnetic relays are devices that are magnetic in nature therefore, any study of protective relaying must include a study of magnetic forces.
- Magnetic lines drawn from North Pole to South Pole and known as the magnetic field or flux of the magnet.
- A strong magnetic field is represented by close magnetic lines.
- Unlike magnetic poles, N-S, attract each other (attraction).
- Like magnetic poles, either N-N or S-S, repel each other.
- Flux density is the number of magnetic field lines per unit area of a section perpendicular to the direction of flux represented by the symbol B.
- Permeability is a measure of the effectiveness of a material as a path for magnetic lines of force as compared with the effectiveness of air.
- Some materials such as iron have high permeability, others such as aluminum have medium permeability and others such as silver and gold have low permeability.
- When a current is passed through a wire it creates a magnetic field around the wire.
- The magnetic field around a wire carrying a current consists of a series of concentric circles.
- The direction of the magnetic field around a wire carrying a current can be predicted using the "right hand screw rule."
- When two parallel conductors are both carrying current their magnetic fields will interact to produce a force of attraction or repulsion between them.
- An electromagnet can be produced by simply feeding a current through a coil of wire that is wrapped around an iron bar.
- The solenoid is a coil wound on iron core and it will appear as a magnetic field with a (**N**) pole at one end and a (**S**) pole at the other opposite end.

- The advantage of the electromagnet when compared with the permanent magnet is that the magnetism of the electromagnet can be switched on and off by a functional switch controlling the coil current.
- Magneto-motive force (mmf) is the strength of a magnetic field in a coil of wire.
- A good magnetic material with high relative permeability can concentrate flux and produce a large value of flux density.
- A relay is essentially an electromagnetic device used to open or close a switch that controls another circuit.

FORMULAS

$B = \frac{\Phi}{A}$ Flux Density per unit area

$H = \frac{N \times I \ (\text{Ampere-Turn})}{\ell \ (\text{meter})}$ (For solenoid)

$\mu = \frac{B}{H}$

Where: μ = Permeability of the core material

GLOSSARY

Flux density (B)	Number of magnetic field lines per unit area
Solenoid	A coil wound on iron core and it will appear as a magnetic field with a (N) pole at one end and a (S) pole at the other opposite end
Permeability(μ)	A measure of the effectiveness of a material as a path for magnetic lines of force as compared with the effectiveness of air
Magneto-motive force (mmf)	Strength of a magnetic field in a coil of wire
Alloy	Mixture of one or more metals
NI	Ampere-Turns as unit of field strength
Relay	An electromagnetic device used to open or close a switch that controls another circuit

REVIEW EXERCISE

Complete by filling in blanks

1. Magnetic lines drawn from _____ Pole to South Pole and known as the ___ field.
2. Unlike magnetic poles ____ each other and like magnetic poles ____ each other.
3. When a current is passed through a wire it creates a _______ field around the wire.
4. When two parallel conductors are both carrying current their magnetic fields will interact to produce a force ___________ or __________ between them.
5. A relay is essentially an electromagnetic device used to open or close a switch that _______ another circuit.
6. Winding the coil around a soft iron core _________ the flux density.

Choose the correct answer:

7. Ampere-turn is the base unit of __________.

   (a) Flux (b) Magnetizing force

   (c) Flux density (d) Magneto-motive force

8. The invisible lines often associated with a magnet are known as____________.

   (a) Flux (b) Reluctance

   (c) Permeability (d) Domains

9. Calculate the missing values:

Problem		(A)	(B)	(C)
Magnetic flux ϕ in	mWb	1	3	1.1
Magnetic flux density B in	T	____________	0.6	____________
Pole surface A	cm^2	20	____________	100

TASK 1.5-1

ELECTROMAGNETIC INDUCTION

OBJECTIVES

Upon completion of this task, the trainees will be able to:

- Demonstrate How Electromagnetic Induction Produces Electric Current.

EQUIPMENT AND MATERIALS

- 1 - Galvanometer
- 1 - Coil
- 1 - Bar magnet

PROCEDURE

1. Receive from the Instructor the following:

   a.- Coil b.- Zero-center Galvanometer c.- Bar magnet
2. Inspect the materials and equipment for good condition.
3. Connect each end of the coil of wire to the terminals on the Galvanometer.
4. Insert the bar magnet into the coil of wire while observing the Galvanometer.
5. Remove the bar magnet from the coil while observing the Galvanometer.
6. Repeat **Steps 4-5** at least three times to observe the Galvanometer needle.
7. Hold the magnet in one hand and move the coil while observing the Galvanometer.
8. Explain to the Instructor, why the Galvanometer needle moves.
9. Return the materials and equipment to their proper location.
10. Clean up after the task is finished.

TASK 1.5-2

RELAY APPLICATION

OBJECTIVES

Upon completion of this task, the trainees will be able to:

- Demonstrate application of magnetism and relay operation.

EQUIPMENT AND MATERIALS

- 1 - Electro-Demonstrator
- 1 - Armature assembly
- 1 - N/O pushbutton switch
- 1 - Small coil
- 1 - Short iron core
- 1 - Lamp

PROCEDURE

1. Receive from the Instructor the following:

   a.- Electro-Demonstrator   b.- Armature assembly
   c.- Small coil   d.- Short iron core
   e.- N/O pushbutton switch   f.- Lamp

2. Connect the circuit and place the coil and the mount on the base plate in front of the armature assembly (Fig. 2-1). Lock the iron core in the coil. Put the core about 1/32 inch (0.8 mm) from the armature. What should happen when current flows through the coil?

3. Press the armature against the coil and turn the Normally Open (NO) screw until it touches the armature. Also, be sure the Normally Closed (NC) screw does not touch the armature in its neutral or resting position. What effect should these armature adjustments have on the current flow through the armature.

   HINT: Current can flow through the NO armature contact points only when the armature is pulled to the coil.

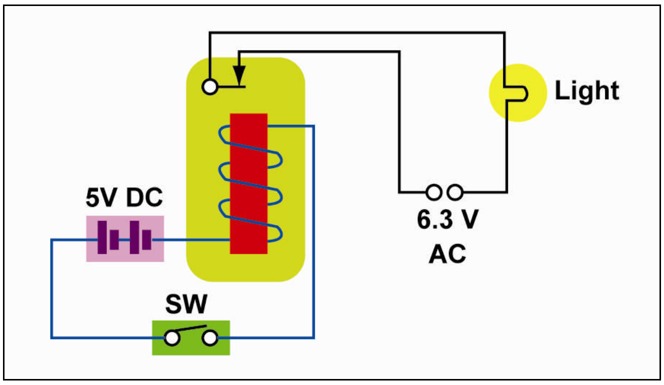
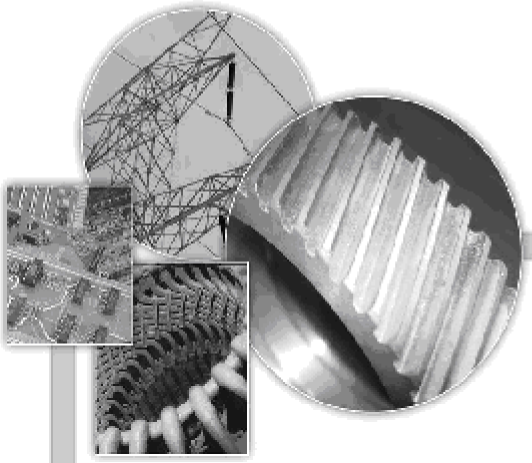


Fig. 2-1 for Task 1.5-2

NOTE

A working relay circuit shows the control circuit on the left and the circuit being controlled by the relay on the right.

4. Connect the lamp and PB-NO switch to the power supply, as shown in Fig. 1 above. Adjust the DC power supply to 5Vdc and the AC power supply to 6.3V AC and observe what happened.
5. Repeat Step 3 but change the DC voltage and the gap between the armature and the core. (Do not change the 6.3 VAC.) What happens?



UNIT 2

AC/DCCIRCUIT FUNDAMENTALS

UNIT-2

AC/DC CIRCUIT FUNDAMENTALS

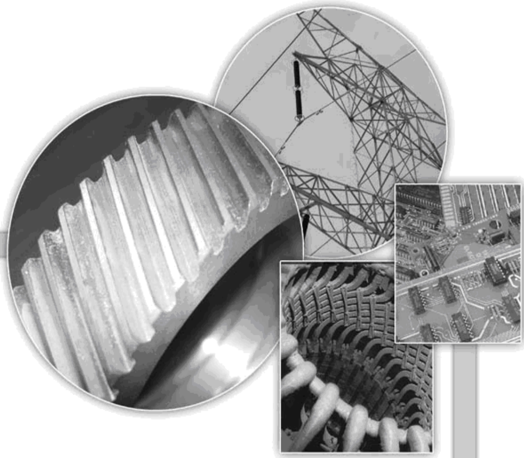
OVERVIEW

In this unit for AC/DC circuit fundamentals, the trainees learn inductance, capacitance, resonant circuits and filters, single and three phase power, power factor.

OBJECTIVES

Upon completion of this unit, the trainees will be able to:

- Analyze properties of inductance and capacitance in AC/DC circuits by Ohm's law.
- Apply Ohm's law to resonant circuits and filters for AC/DC analysis.
- Discuss the procedures to correct power factors in a power system.
- Analyze the single and three phase power circuits.



LESSON 2.1

INDUCTANCE

LESSON 2.1

INDUCTANCE

OVERVIEW

This lesson explains the properties of inductance and its applications in series and parallel AC/DC circuits.

OBJECTIVES

Upon completion of this lesson, the trainees will be able to:

- List three factors that affect the amount of inductance of a coil.
- Identify types of inductors.
- State the formulas for total inductance of inductors connected in series and parallel.

Task 2.1-1: RL Combination Circuits

INTRODUCTION

In this lesson, you'll study about electrical components that oppose the flow of AC by temporarily storing energy as magnetic fields. These devices are called **inductors** and their action of inducing magnetic field by current flow is known as **Inductance**. **Inductors** often, but not always, consist of wire coils. Sometimes a length of wire, or a pair of wires, is used as an inductor.

SELF-INDUCTION

Before you learn about self-induction, you must first differentiate between two conditions that can exist in any DC circuit. The first is called the **transient-state** condition while the other is called the **steady state** condition. Up to this point, you have considered only the steady-state condition.

Most DC circuits reach the steady-state condition within a fraction of a second after power is applied. In this condition, the current in the circuit has reached the value computed by Ohm's Law. However, because of other characteristics of the circuit, the current does not reach the steady-state value, instantaneously. There is a brief period called the **transient time** in which the current **builds up** to its steady-state value.

During the transient time, when the current is changing from zero to some definite value, the phenomenon called **Self-Induction** occurs. Remember that a magnetic field builds up around any conductor when current flows through that conductor.

The amount of current determines the strength of the magnetic field. As current flow increases, field strength increases, and as current flow decreases, field strength decreases.

Any change in current causes a corresponding change in the magnetic field surrounding the conductor.

A change in the magnetic field surrounding the conductor induces a voltage in the conductor. This self-induced voltage **opposes** the change in current. This is known as **counter emf** (electro motive force is the external work consumed per unit of charge to produce an electric potential difference across two open-circuited terminals). This opposition causes a delay in the time it takes current to reach its new steady.

INDUCTANCE

Inductance is the ability of a device or circuit to oppose a change in current flow. Inductance may also be defined as the ability to induce a counter emf when there is a change in current flow. Induction and inductance are easily confused. Therefore, it is necessary to discuss the difference between them.

Induction is the action of inducing an EMF when there is a change in current. That is, obviously then, induction exists only when a **change** in current occurs.

Inductance is the ability to cause an induced voltage when change in current occurs. Thus, inductance is a physical property. Like Resistance, Inductance exists whether current is flowing or not. The unit of measurement for inductance is the Henry (**H**).

A Henry is the amount of inductance that causes EMF of 1 V be induced into a conductor when the current through the conductor changes at the rate of 1 Ampere per second. In most electronics applications, the Henry is a large quantity.

For this reason, quantities milli-Henry (**mH**) and micro-Henry (**μH**) are more commonly used. The symbol for inductance is **L**. Thus, the statement “the inductance is 10 milli-Henrys” can be written as an equation: **L = 10 mH**

INDUCTORS

Because a magnetic field forms around any conductor when current flows through it, every conductor has a certain value of inductance. However, with short lengths of wire, the inductance value is small. A device that is designed to have a specific value of inductance is called an **Inductor**. Inductors come in a variety of values from micro-Henries to several Henries. The inductor (Fig. 2.1-1) consists of a length of wire coiled around some type of core. For this reason, the inductor is often called a coil.

An inductor is a component designed to have a specific inductance. Examples of inductors, or devices having inductance, are transformers, chokes, coils, relays, and motors.

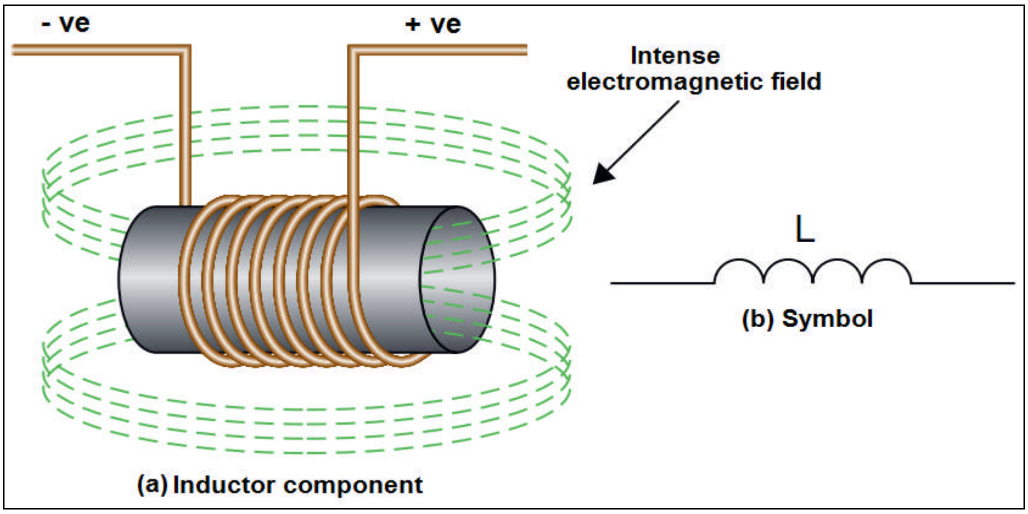


Fig. 2.1-1 Inductor Components and Symbol

FACTORS AFFECTING INDUCTANCE OF COILS (Fig. 2.1-2)

A. NUMBER OF TURNS

Inductance varies directly with the square of the number of turns (N).

B. PERMEABILITY OF CORE

Inductance varies directly with the permeability (μ) of the core material.

C. CROSS-SECTIONAL AREA OF COIL

Inductance varies directly with the cross-sectional area (A) of the coil.

D. LENGTH OF COIL

Inductance varies inversely with the length **(l)** of the coil.

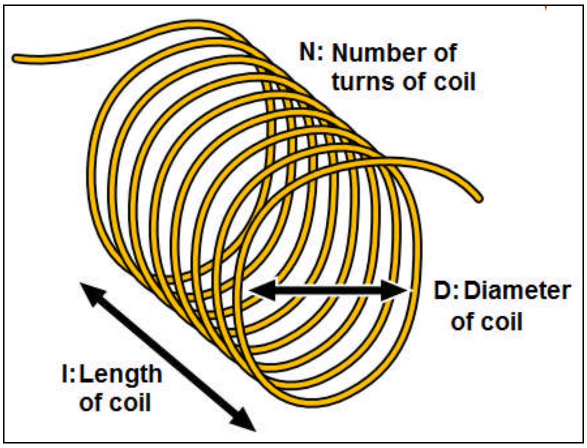


Fig. 2.1-2 Factors Affecting Inductance of Coils

An approximation of inductance for any coil can be found with this formula

$$L = \frac{N^2 \mu A}{l} \text{ Henery}$$

TYPES OF INDUCTORS

- **air core**
- **iron core**

Fig. 2.1-3(a) shows a common **air core** inductor. These devices are simply a coil of wire wrapped onto a coil form. Fig. 2.1-3(b) shows a common **iron core** inductor much like transformers, inductors can benefit from magnetic cores.

Core materials can include ferrite, powdered iron, laminated iron and other materials.

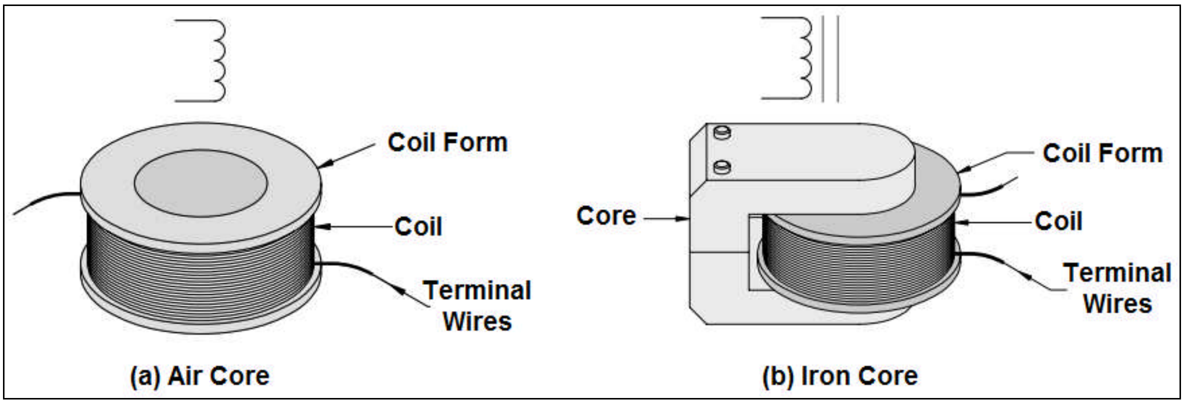


Fig. 2.1-3 Types of Inductors

SIMPLE INDUCTIVE CIRCUIT

In a resistive circuit, current change is considered instantaneous. If an inductor is used, the current does **not** change as quickly.

For the purpose of explanation, a DC circuit is used here to describe the operation of an inductor. There will always be some amount of resistance and inductance in any circuit. The electrical wire used in the circuit has some resistance and inductance. In addition, inductors also have resistance.

In the following circuit (Fig. 2.1-4), initially the switch is in position **2**, and there is no current flowing through the ammeter (**A**). When the switch is moved to position **1**, current will rise rapidly at first, and then more slowly as the maximum value is approached.

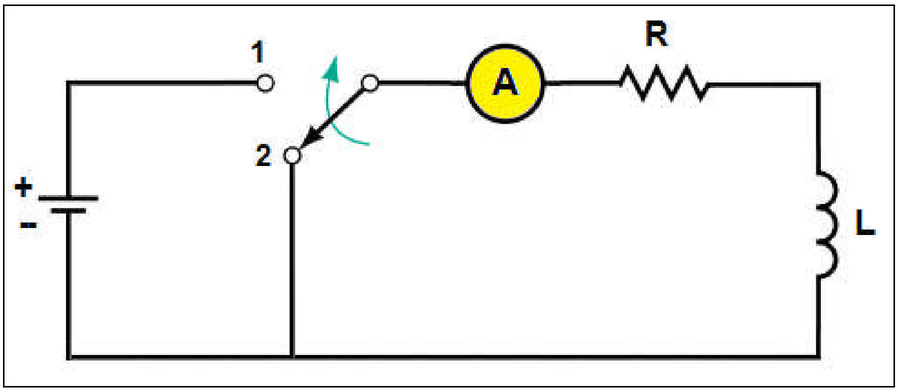


Fig. 2.1-4 Simple Inductive Circuit

INDUCTIVE TIME CONSTANT

The time required for the current to rise to its maximum value is determined by the ratio of inductance (in henrys) to resistance (in ohms).This ratio is called the **time constant** of the inductive circuit. A time constant is the time (in seconds) required for the circuit current to rise to 63.2% of its maximum value. When the switch is closed in the previous circuit (Fig. 2.1-4), current will begin to flow. During the first time constant current rises to 63.2% of its maximum value. During the second time constant, current rises to 63.2% of the remaining 36.8%, or a total of 86.4%. It takes about five time constants (Fig. 2.1-5) for current to reach its maximum value.

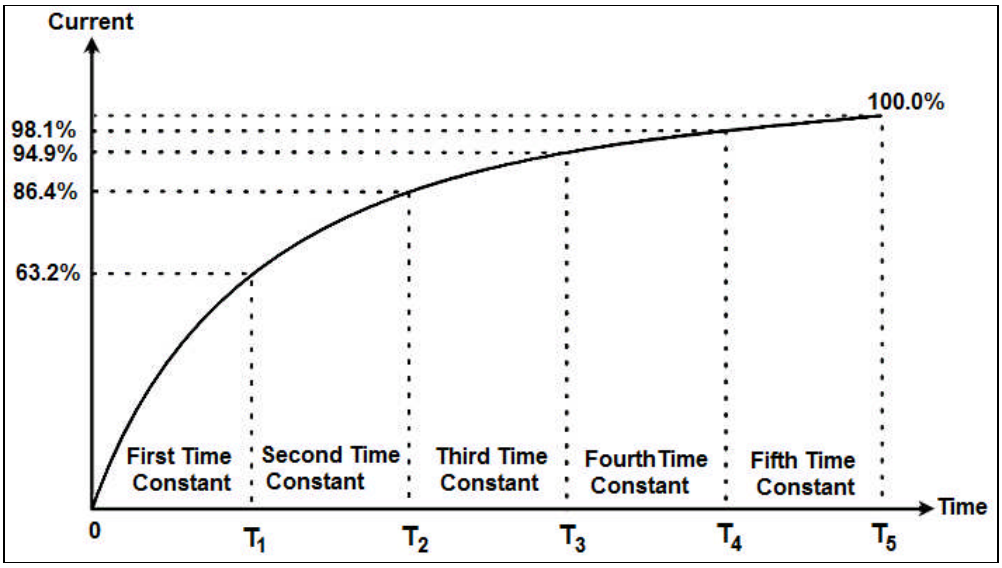


Fig. 2.1-5 Energizing Current in Inductor

Similarly, when the switch in the previous circuit (Fig. 2.1-4) is returned to position **2**, the magnetic field around the inductor will begin to collapse, returning stored energy to the circuit, and it will take about five time constants (Fig. 2.1-6) for current to reach zero.

The time constant for a series **RL** circuit is:

$$t = \frac{L}{R}$$

Where: t = time (seconds) L = Henries (H) R = Ohms (Ω)

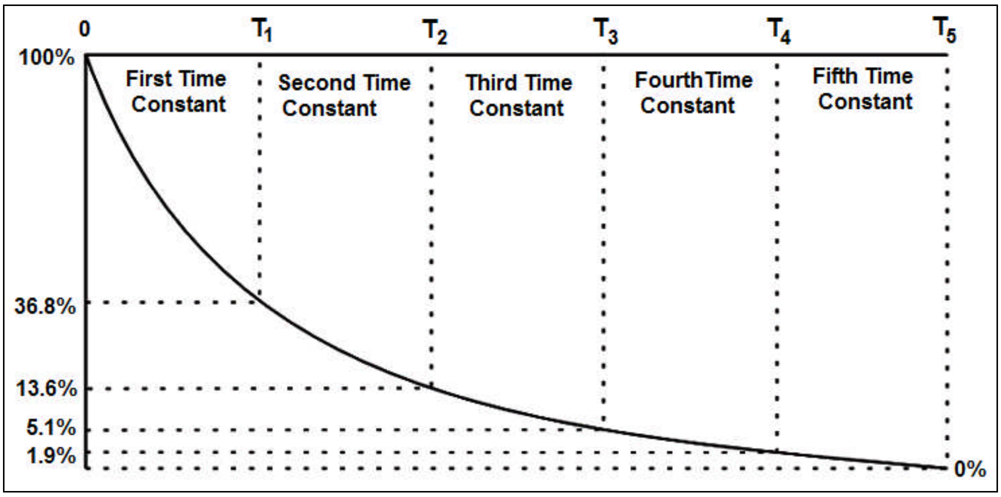


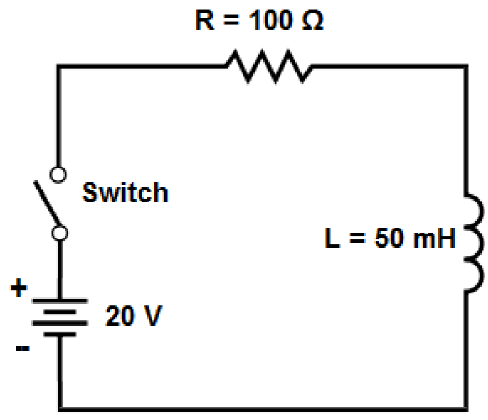
Fig. 2.1-6 De-energizing Current in Inductor

EXAMPLE 2.1-1

A series **RL** circuit has a resistance of 1 kΩ and an inductance of 1 mH. What is the time constant?

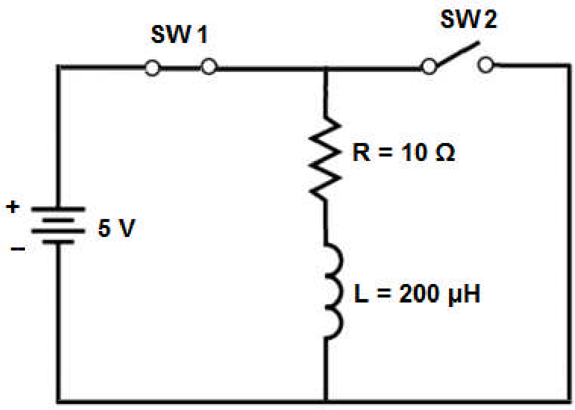
SOLUTION

$$t = \frac{L}{R} = \frac{1\ \text{mH}}{1\ \text{k}\Omega} = \frac{1\times10^{-3}\ \text{H}}{1\times10^{3}\ \Omega} = 1\times10^{-6}\ \text{s} = 1\ \mu\text{s}$$

EXAMPLE 2.1-2 Calculate the time constant for the circuit shown in Fig. 2.1-7. Then determine the current and the time at each time constant interval, measured from the instant the switch is closed.	 Fig. 2.1-7 Example 2.1-2

SOLUTION

$I_{final} = \frac{V_S}{R} = \frac{20\,V}{100\,\Omega} = 0.2\,A$	At 1T =0.5 ms:	i= 0.63(0.2 A) = 0.126 A
$T = \frac{L}{R} = \frac{50\,mH}{100\,\Omega} = 0.5\,ms$	At 2T = 1 MS:	i= 0.86(0.2 A) = 0.172 A
	At 3,r = 1.5 ms:	i= 0.95(0.2 A) = 0.190 A
	At 4T = 2 ms:	i= 0.98(0.2 A) = 0.196 A
	At 5T = 2.5 ms:	i= 0.99(0.2 A) = 0.198 A ≈ 0.2 A

EXAMPLE 2.1-3 In Fig. 2.1-8, switch (sw1) is opened at the instant that switch (sw2) is closed. a. What is the time constant? b. What is the initial coil current at the instant of switching? c. What is the coil current at 1T? Assume steady state current through the coil before switch change.	 Fig. 2.1-8 Example 2.1-3

SOLUTION

a. $t = \frac{L}{R} = \frac{200\ \mu H}{10\,\Omega} = \frac{200 \times 10^{-6}\ H}{10\,\Omega} = 20 \times 10^{-6}\ s = 20\,\mu s$

b. Current cannot change instantaneously in an inductor. Therefore, the current at the instant of the switch change is the same as the steady state current:

$I = \frac{E}{R} = \frac{5V}{10\,\Omega} = 0.5\,A$

c. At 1_T, the current has decreased to 37% of its initial value:

I = 0.37 x (0.5 A) = 0.185 A

STEADY STATE CONDITION IN RL (DC) CIRCUIT

When direct current flows in an inductor, there is no induced voltage. There is, however, a voltage drop due to the winding resistance of the coil. In DC the inductor behaves like **a short circuit**.

Energy is stored in the magnetic field according to the formula:

$$\mathbf{W = \frac{1}{2} L\ I^2}$$

Where: W = Energy (J)   L = Inductance (H)   I = Current (A)

The only energy loss (converting to heat) occurs in the winding resistance is

$\mathbf{P = I^2 R_w}$ **(Watt)**

INDUCTORS IN COMBINATION

Inductors like other components can be connected in series, parallel (Fig. 2.1-9), or series-parallel combinations. The following relationships give series and parallel connections of inductors.

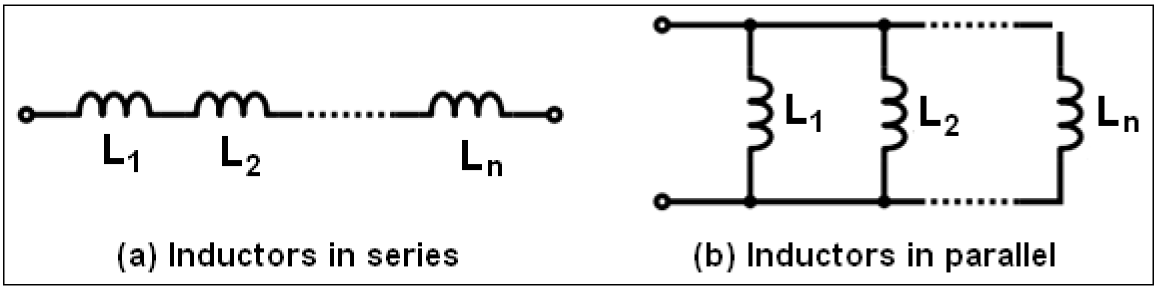


Fig. 2.1-9 Inductors in Series and Parallel

- $L_T = L_L + L_2 + L_3 + \ldots L_n$ **Inductors in series**
- $L_T = \dfrac{1}{\dfrac{1}{L_1} + \dfrac{1}{L_2} + \dfrac{1}{L_3} + \ldots \dfrac{1}{L_n}}$ **Inductors in parallel**

INDUCTORS IN AC CIRCUITS

In a purely resistive AC circuit, resistance is the only opposition to current flow. In an AC circuit with only inductance, capacitance, or both inductance and capacitance, but no resistance, opposition to current flow is called **reactance,** designated by the symbol "**X**".

Total opposition to current flow in an AC circuit that contains both reactance and resistance is called **impedance,** designated by the symbol "**Z**". Just like resistance, reactance and impedance are expressed in ohms.

INDUCTIVE REACTANCE

Inductance only affects current flow when the current is changing. Inductance produces a self-induced voltage (counter emf) that opposes changes in current. In an AC circuit, current is changing constantly.

Inductance in an AC circuit, therefore, causes a continual opposition. This opposition to current flow is called **inductive reactance** and is designated by the symbol "X_L".

Inductive reactance is proportional to both the inductance and the frequency applied. The formula for inductive reactance is:

$\mathbf{X_L = 2\,\pi\,f\,L}$

Where:

2 π = Constant =6.28 **f** = Frequency (Hz) **L** = Inductance (H)

From the formula you can see that $\mathbf{X_L}$ increases as the frequency of the circuit current or the inductance of the coil increases.

For a 60 hertz circuit containing a 10 mh inductor, the inductive reactance is:

$X_L = 2\,\pi\,f\,L$

$X_L = 2\,\pi\,(60\text{ Hz})\,(10\text{x }10^{-3}\text{ H})$

$X_L = 3.768\,\Omega$

OHM'S LAW IN INDUCTIVE CIRCUITS

The reactance of an inductor is analogous to the resistance of a resistor. In fact, $\mathbf{X_L}$, just like **R**, is expressed in **Ohms**. Since inductive reactance is a form of opposition to current, **Ohm's** law applies to inductive circuits as well as to resistive circuits and it is stated as follows: $\mathbf{V = I \times X_L}$

When applying Ohm's law in AC circuits, you must express both the current and the voltage in the same way, that is, both in **rm**s (The root-mean-square value of on alternating voltage is the equivalent DC voltage that can deliver the same amount of energy to a resistor), both in peak and so on.

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EXAMPLE 2.1-4

Determine the rms current in the Fig. 2.1-10

SOLUTION

$X_L = (2\pi\ f\ L)$

$X_L = 2\pi\ (10x\ 10^3\ Hz)(100\ x\ 10^{-3}\ H)$

$X_L = 6.283\ k\ \Omega$

$I_{rms} = V_{rms} / X_L$

$I_{rms} = 5\ V / 6283\Omega = 795.8\ \mu A = 0.796\ mA$

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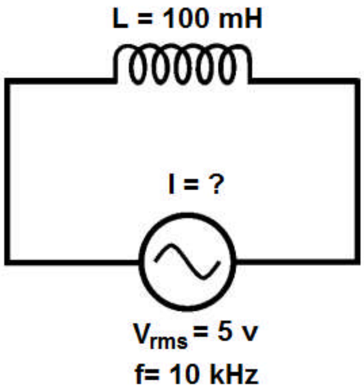

Fig. 2.1-10 Example 2.1-4

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POWER IN INDUCTOR

When power flows into an inductor, energy is stored in its magnetic field. When the field collapses, this energy is returned to the circuit. For an ideal inductor, $R = 0$ ohm and hence no power is dissipated; thus, an ideal inductor has zero power loss.

Fig. 2.1-11 shows the power curve that results from of pure inductor current and voltage.

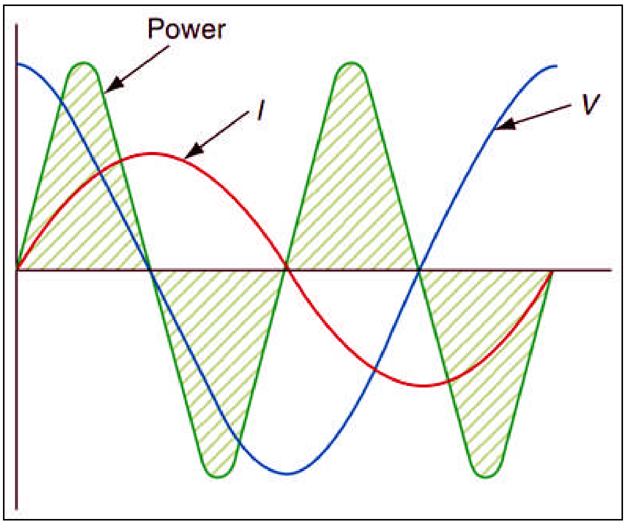


Fig. 2.1-11 Power Curve For pure Inductor

INSTANTANEOUS POWER (P_{INST})

The product of **V** and **I** gives instantaneous power **(P_{inst})**. At points where **V** or **I** is zero, P_{inst} is also zero. As you can see in Fig. 2.1-11, the power follows a sinusoidal curve. Positive values of power indicate that energy is stored by the inductor. Negative values of power indicate that energy is returned from the inductor to the source.

Note that the power fluctuates at a frequency twice that of the voltage or current as energy is alternately stored and returned to the source.

TRUE POWER (P)

Ideally, all of the energy stored by an inductor during the positive portion of the power cycle is returned to the source during the negative portion. No net energy is consumed in the inductance, so the power is zero. Practically, because of winding resistance in a practical inductor, some power is always dissipated.

$$P = (I_{rms})^2 R$$

Where: **P** = True power (W) **R =** Winding resistance (Ω)

REACTIVE POWER (Q)

The rate at which an inductor stores or returns energy is called its reactive power, Q The reactive power is a non-zero quantity, because at any instant in time, the inductor is actually taking energy from the source or returning energy to it. Reactive power does not represent an energy loss. The following formulas apply:

$$Q = (V_{rms})^2 / X_L = (I_{rms})^2 X_L$$

Where: **Q** = Reactive power (Var)

EXAMPLE 2.1-5

A 10 V rms signal with a frequency of 1 kHz is applied to a 10 mH coil. Determine the reactive power (Q).

SOLUTION

$X_L = (2\pi\ f\ L) = 2\pi\ (1 \times 10^3\ Hz)\ (10 \times 10^{-3}\ H) = 62.83\ \Omega$

$I_{rms} = (V_{rms} / X_L) = 10\ V / 62.83\Omega = 0.159\ A$

$Q = (I_{rms})^2\ X_L = (0.159\ A)^2 \times 62.83\ \Omega = 1.588\ Var$

R-L CIRCUITS

Most circuits contain resistance as well as reactance. The total opposition to current flow in a circuit containing resistance and reactance is referred to as impedance (**Z**) and is measured in Ohms. You cannot add resistance and reactance directly; you must combine them, vectorially.

RL CIRCUITS

In series **RL circuit** connected to A.C. voltage (Fig.2.1-12) the following occur:

a. Current lags voltage by 90° in a pure inductive circuit

b. Current and voltage are in phase in a pure resistive circuit

c. current lags voltage between 0°' and 90° depending upon:

- Relative amounts of **R** and **L** present
- Frequency of applied voltage or current (angular velocity)

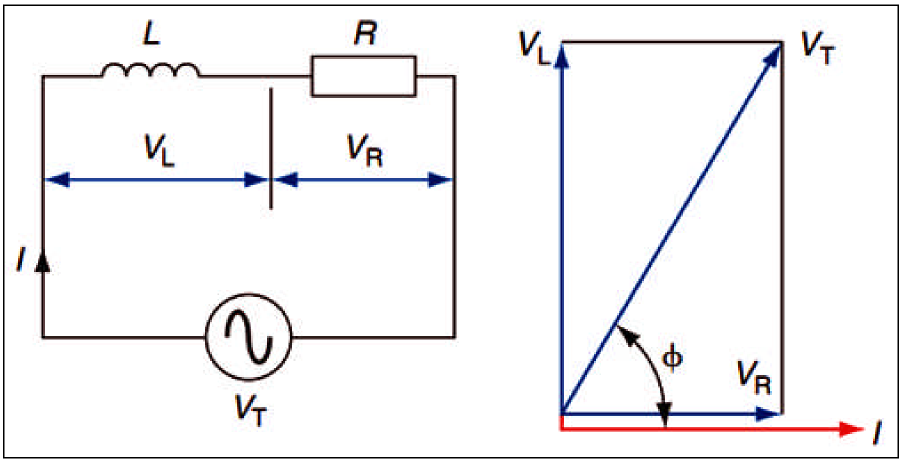


Fig. 2.1-12 A Series RL Circuit and Phasor Diagram

As shown in Fig. 1-6:

a. Current is same in **R** and in **L**

b. Voltage across resistor (**V_R**) is in phase with current

c. Voltage across inductor (**V_L**) is 90° ahead of current

Applied voltage (**V_T**) is vector sum of the two out-of-phase voltages and equals

$$V_T = \sqrt{(V_R)^2 + (V_L)^2}$$

Dividing each quantity by current results in impedance formula:

$$Z = \sqrt{(R)^2 + (X_L)^2}$$

Phase angle θ is the angle whose cosine = **Cos** θ = (**V_R / V_T**)

Also:

$$\theta = \arctan (X_L / R)$$

EXAMPLE 2.1-6

A coil of 0.15 H is connected in series with a 50 Ω resistor across a 100V, 60Hz supply (Fig. 2.1-13). Calculate (a) the reactance of the coil, (b) the impedance of the circuit and (c) the current.

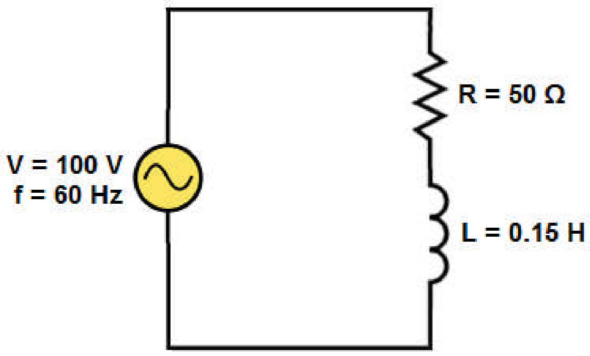


Fig. 2.1-13 Example 2.1-6

SOLUTION

a. $X_L = 2 \times 3.14 \times 60 \times 0.15 \times = 75.461\ \Omega$

b. $Z = \sqrt{(50)^2 + (56.52)^2} = 75.461\ \Omega$

c. $I = 100/75.461 = 1.325$ A

PARALLEL RL CIRCUIT

The expression for the impedance of basic parallel RL circuit is:

$$Z = R \times X_L \ / \ \sqrt{(R)^2 + (X_L)^2}$$

The phase angle between the applied voltage and the total current is

$$\theta = \arctan (R / X_L)$$

EXAMPLE 2.1-7

In parallel RL circuit (Fig. 2.1-14) R=100 Ω, X_L = 50 Ω. Calculate Z, θ of the circuit?

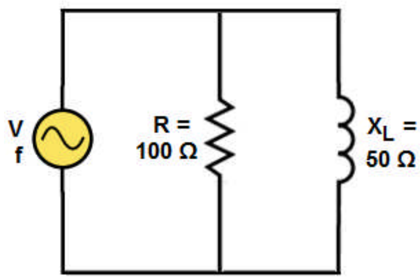


Fig. 2.1-14 Example 2.1-7

SOLUTION

$$Z = 100\ \Omega \times 50\ \Omega\ /\ \sqrt{(100\ \Omega)^2 + (50\ \Omega)^2} = 44.72\ \Omega$$

θ = arctan (R/ X_L) = arctan (100/ 50) = arctan (2) = 3.44°

SUMMARY

- Inductance is the ability of a device or circuit to oppose a change in current flow.
- Induction is the action of inducing an EMF when there is a change in current.
- A Henry is the amount of inductance that causes EMF of 1 V be induced into a conductor when the current through the conductor changes at the rate of 1 Ampere per second.
- In most electronics applications, the Henry is a large quantity. For this reason, quantities milli-Henry (mH) and micro-Henry (μH) are more commonly used.
- A device that is designed to have a specific value of inductance is called an Inductor.
- The inductor consists of a length of wire coiled around some type of core.
- Examples of inductors, or devices having inductance, are transformers, chokes, coils, relays, and motors.
- Inductance varies directly with the square of the number of turns (N).
- Inductance varies directly with the permeability (μ) of the core.
- Inductance varies directly with the cross-sectional area (A) of the core.
- Inductance varies inversely with the length (l) of the core.
- .
- In DC the inductor behaves like a short circuit.
- In an AC circuit with only inductance, capacitance, or both inductance and capacitance, but no resistance, opposition to current flow is called reactance.
- When power flows into an inductor, energy is stored in its magnetic field.
- The rate at which inductor stores or returns energy is called its reactive power.

FORMULAS

$L = \frac{N^2 \mu A}{l}$ Henery (H) Inductance in terms of physical parameters

$t = \frac{L}{R}$

Where: t = time (seconds) L = inductance (Henries) R = resistance (Ω).

$L_T = L_l + L_2 + L_3 + \ldots L_N$ Inductors in series

$$L_T = \frac{1}{\frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} + \ldots \frac{1}{L_n}}$$ Inductors in parallel

$X_L = 2 \pi f L \ \Omega$ Inductive reactance

Where:

2π = Constant =6.28 f = Frequency (Hz) L = Inductance (H)

Impedance in series

$$Z = \sqrt{(R)^2 + (X_L)^2} \quad \Omega$$

$\theta = \arctan (X_L / R)$

Impedance in parallel

$$Z = R \times X_L \ / \ \sqrt{(R)^2 + (X_L)^2} \quad \Omega$$

$\theta = \arctan (R / X_L)$

GLOSSARY

Inductor	A device that introduces inductance in an electrical circuit (usually a coil)
Inductance	The property of an electric circuit when a varying current induces an EMF in that circuit or another circuit
Self-Inductance	The property of an electric circuit when an EMF is induced in that circuit by a change of current
Henry	The unit of inductance
Permeability	The measure of the ease with which material will pass lines of flux
Time Constant	The time required for the inductor current to change by 63% and equals the inductance divided by the resistance
Reactance	A opposition to alternating current resulting from circuit
Joule	A basic unit of electrical energy. 1 Joule is equal to 1 watt-second or the amount of energy transferred in one second when the power is one watt

REVIEW EXERCISE

1. Calculate the total inductance and total reactance at 60 Hz frequency in below circuit (Fig. 2.1-15)

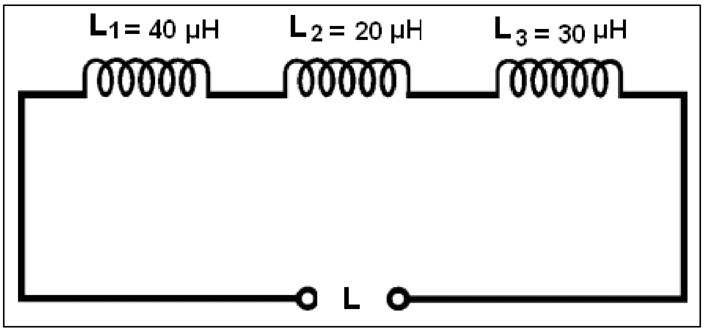


Fig. 2.1-15

2. Calculate the total inductance and total reactance at 60 Hz frequency in below circuit (Fig. 2.1-16)

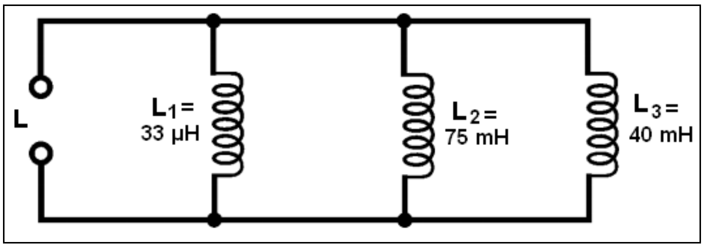


Fig. 2.1-16

3. Determine the time constant for each of the following series **R-L** combinations:

   a. R = 100 Ω, L = 100 μH

   b. R = 4.7 kΩ, L = 10 mH

   c. R = 1.5 MΩ, L = 3 H

4. In a series **R-L** circuit, determine how long it takes the current to build up to its full value for each of the following:

   a. R= 50Ω, L= 50 μH

   b. R = 22 kΩ, L = 100 mH

   c. R = 3300Ω, L = 15 mH

TASK 2.1-1

RL COMBINATION CIRCUITS

OBJECTIVES

Upon completion of this task, the trainees will be able to:

- Demonstrate the characteristics of inductance.
- Show a method of measuring inductance in a RL series circuit.

MATERIAL/EQUIPMENT

- (1) ET-3100 Electronic Design Experimenter or equivalent
- (1) VOM with test leads
- (1) Oscilloscope
- (1) Alignment tool
- (1) 100 Ω, 1/2 watt resistor
- (1) Variable conductor
- (1) Neon lamp

PROCEDURE

1. Cut two 2-inch lengths of #22 hook-up wire. Strip 3/8 inch insulation from the ends of each of the wires. Solder one end of each wire to the two terminals on the variable inductor, (Fig. 1-1).

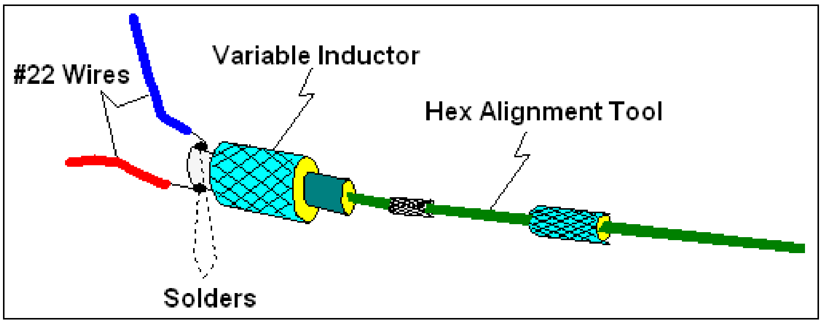


Fig. 1-1 Step 1

2. Construct the experimental circuit shown in Fig. 1-2. Connect the variable inductor in parallel with the neon lamp on the ET-3100 breadboard. Then connect a **DC** voltage to the choke as indicated. Leave the lead coming from the **GND** output terminal of the power supply disconnected. This lead will be used as a switch to connect and disconnect the DC voltages from the choke.

   You will use this circuit to demonstrate the effect of **DC** on an inductor. The neon lamp will provide a visual indication of this effect.

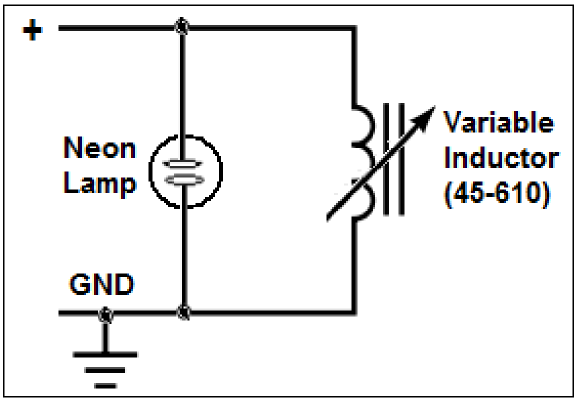


Fig. 1-2 Step 2

3. Set the **+** voltage control on the **ET-3100** power supply to 7.5 volts.
4. Connect the **GND** lead from the power supply to the lead of the neon lamp or plug the wire into the bread board socket and note the effect this has on the neon lamp.

   Does the neon bulb light? ____________________________________
5. Disconnect the **GND** power supply lead from the neon lamp. What is the condition of the lamp when the lead is removed? ____________________

   Repeat this procedure by alternately connecting and disconnecting the GND lead. Note the effect on the lamp each time the voltage is applied and disconnected.

   It takes approximately 67 volts to cause the neon lamp to light. Based on this fact, how do you account for the result you noted in the previous steps with only 7.5 volts applied? ____________________________________

6. Adjust the power supply output voltage to 15 volts. Then repeat **Steps 3-4** noting the effect on the neon lamp as the voltage is connected and disconnected from the circuit, (Fig. 1-3).

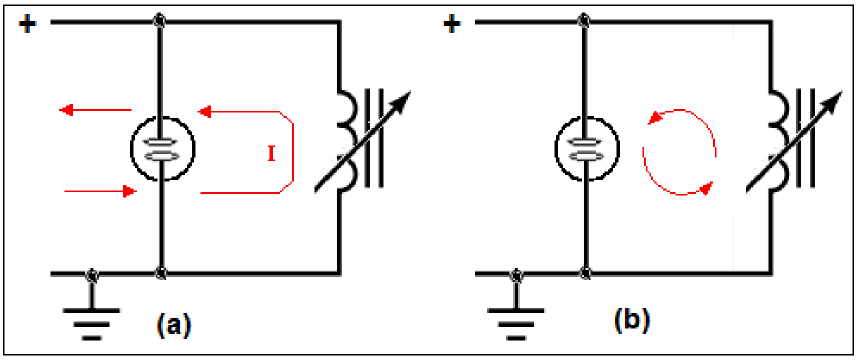


Fig. 1-3 Circuit for Discussion after Step 6

7. Construct the circuit in Fig. 1-4(a). You will use this circuit to demonstrate a method of measuring the inductance of the circuit. Be sure that the **Frequency Range Switch** is in the **Low** position. Adjust the FREQ control so that the output from the generator is **2000 Hz**.

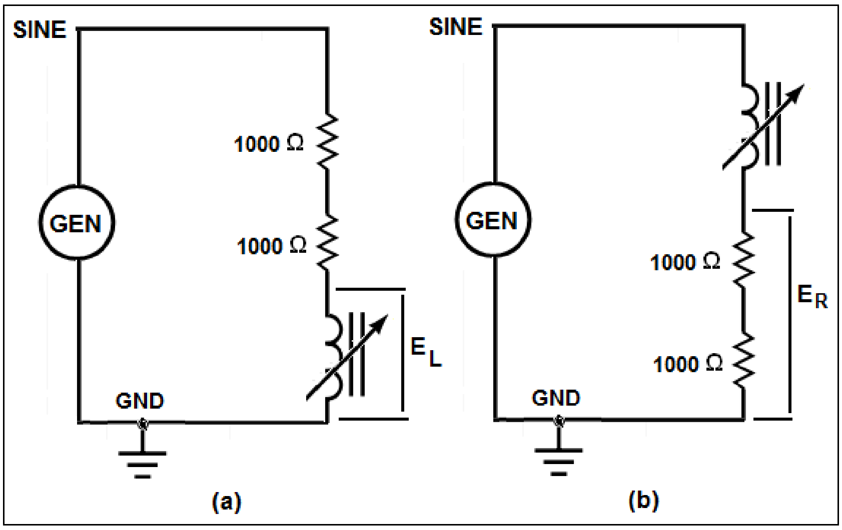


Fig. 1-4 Circuit for Step 7

8. Turn **ON** the Trainer and measure the **AC** voltage applied to the circuit. This is the voltage between the **SINE** and **GND** terminal on the **ET-3100**. Record this value below.

   AC applied = ________________volts.

9. Measure the voltage across the inductor and record this voltage below:

   $\mathbf{E_L}$ = __________________ volts.

10. Turn **OFF** the Trainer and reverse the leads from the generator so that you have the circuit shown in Fig. 1-4(b).

11. Turn the Trainer **ON** and measure the voltage drop across the two resistors. Record the resistor voltage drops below:

    $\mathbf{E_{R1}}$ =____________________volts.

    $\mathbf{E_{R2}}$ =____________________volts.

12. Using the voltage values that you measured in the previous steps, construct a vector diagram showing the relationship between these voltages.

13. Compute the current flowing in the circuit using the resistor drop and the resistor's value. **I** =____________________ Amperes.

14. Compute the inductive reactance of the choke using the circuit current and inductive voltage drop $\mathbf{X_L}$ =___________________Ω

15. Compute the total circuit impedance and record this value in the space provided.

    $\mathbf{Z_T}$ =___________________Ω

16. Compute the circuit inductance using the reactance and the frequency of operation. Record the value of inductance **L**= _____________ Henry.

17. Compute the circuit phase shift. Record the phase angle below.

    θ= _____________degree

18. Turn off the power and disconnect the variable inductor from the circuit. Use the Ohmmeter to measure the DC resistance of the inductor. Record this value of resistance in the space provided.

    DC Resistance of **L** = __________________ Ω

19. Using the value of inductive reactance computed in Step 14, calculate the **L** of the inductor. Record this value. **L** = _____________

20. Construct the circuit shown in Fig. 1-5(a). Again, the sine wave generator on the **ET-3100** will be used as the signal source. You will use this circuit to determine the maximum and minimum values of inductance for the inductor. In addition, you will demonstrate how inductive reactance varies with changes of inductance and frequency.

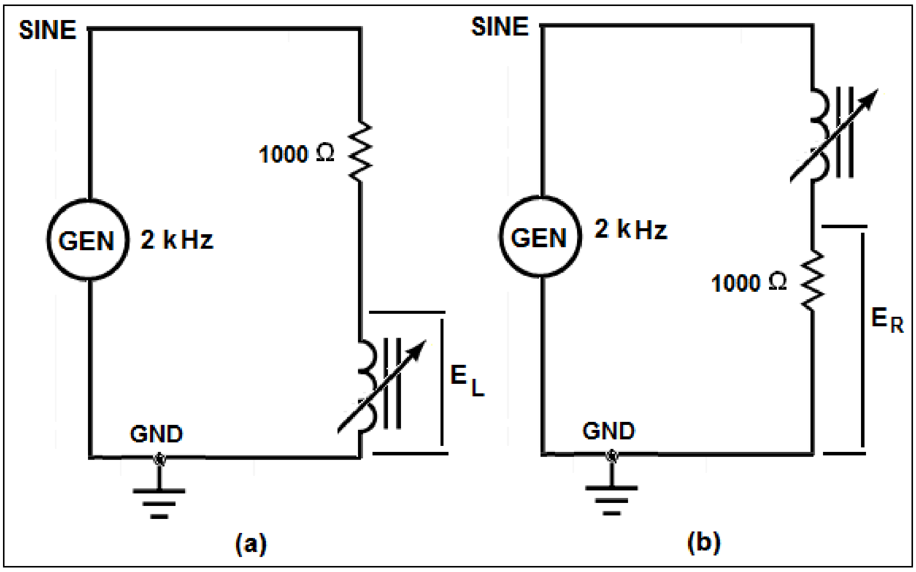


Fig. 1-5 Step 20

21. Make sure that the **RANGE Switch** on the Trainer is set to the **LOW** position and that the **FREQ** dial is set to the **2000 Hz** position marked on the front panel. Turn the ET-3100 **ON**.

22. Connect the voltmeter across the inductor so that you can measure the voltage drop across the inductor. Now, use the plastic hex-alignment tool to adjust the variable inductor. Turn the core first in one direction and then in the other. Once you have adjusted the core for maximum voltage drop across the inductor, record this voltage in the space provided: $\mathbf{E_{L(max)}}$ = _________________ volts.

23. Reverse the leads from the generator so that the circuit configuration appears like the one in Fig. 1-5(b). Measure the voltage across the resistor and record it in the space provided. $\mathbf{E_{R\,(min)}}$ = _____________ volts.

24. Using the voltage values measured above and the other circuit values shown in Fig. 1-5, compute the inductance of this coil and record below.

    L = ________________________ Henrys.

25. With the voltmeter connected across the 1000 Ω resistor, adjust the variable inductor so that maximum voltage is indicated on the voltmeter. Record the voltage across the resistor in the space provided. $\mathbf{E_{R\,(max)}}$ = _____________ volts.

26. Reverse the leads and measure the voltage across the inductor.

    $\mathbf{E_{L\,(min)}}$ = _____________ volts.

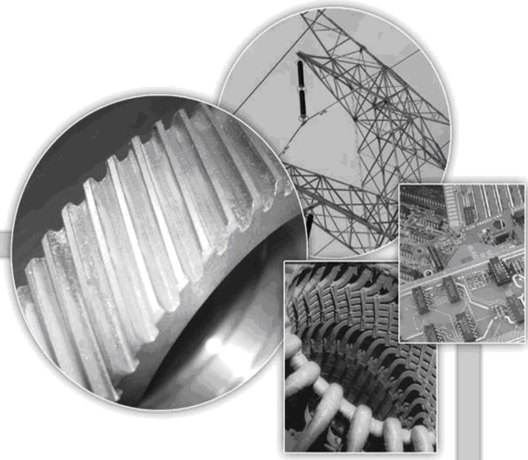
27. Using these voltage values along with the other known circuit values to compute the inductance of the coil and record. **L** = _________________ Henrys.

28. With the voltmeter across the inductor, use the hex-alignment tool to adjust the coil core. Adjust the core so it is moved down toward the bottom of the coil where the connection terminals are. Observe the voltage as you make the adjustment. Next, adjust the coil in the opposite direction so that the core passes up through the coil and then toward the top near the metal mounting tabs. Observe the voltage with respect to the position of the core. Then complete the following statement.

    As the core is moved out of the coil, the voltage across the coil:

    (Increases/decreases) ____________

    Therefore, the inductance has: (increased /decreased) ____________



LESSON 2.2

CAPACITANCE

LESSON 2.2

CAPACITANCE

OVERVIEW

This lesson deals with capacitor characteristics and its applications in AC/DC circuit analysis.

OBJECTIVES

Upon completion of this lesson, the trainees will be able to:

- Describe the function and construction of capacitors.
- Describe the process of charging and discharging.
- List three factors that affect the amount of capacitance.
- Identify types of capacitors.

Task 2.2-1: Capacitor Charge and Discharge

Task 2.2-2: Capacitors in Series and Parallel

Task 2.2-3: Capacitor applications

INTRODUCTION

Electrical components can oppose the flow of AC in three ways, two of which you've studied about. Resistance slows the flow of AC or DC charge carriers. Inductance impedes the flow of AC charge carriers by temporarily storing the energy as a magnetic field. **Capacitance**, about which you'll study in this lesson, **impedes** the flow of **AC** charge carriers by temporarily storing the energy as an **electric field**.

A device especially designed to have a certain value of capacitance is called a **capacitor** that has the ability to store electrons and release them at a later time.

CAPACITORS

A capacitor consists of two conductors separated by an insulator. One of its basic forms is the parallel-plate capacitor (Fig. 2.2-1). It consists of two metal plates separated by a non-conducting material (i.e. an insulator) called a **dielectric.** The dielectric may be air, oil, mica, plastic, ceramic, or other suitable insulating material.

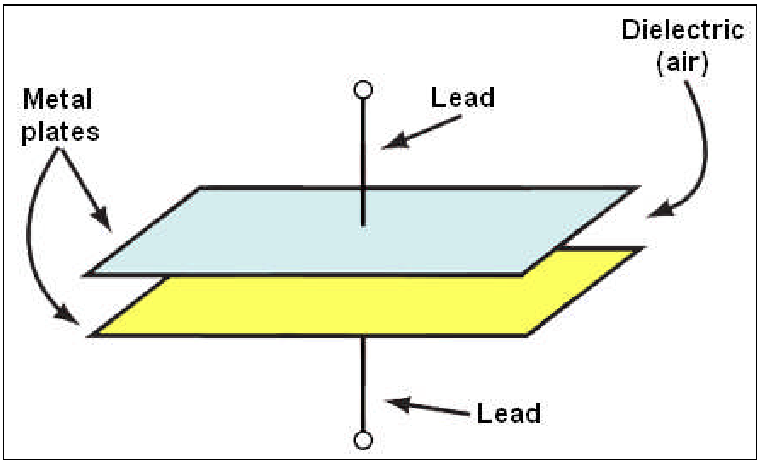


Fig. 2.2-1 Basic Parallel Place Capacitor

Fig. 2.2-2 shows construction of a typical tubular polystyrene capacitor. Additional sheets of paper are placed on the top and bottom of the foil sheets. Then the sheets are

wound into a compact cylinder. Leads are attached to each of the foil sheets. Finally, the entire unit is sealed into a permanent package.

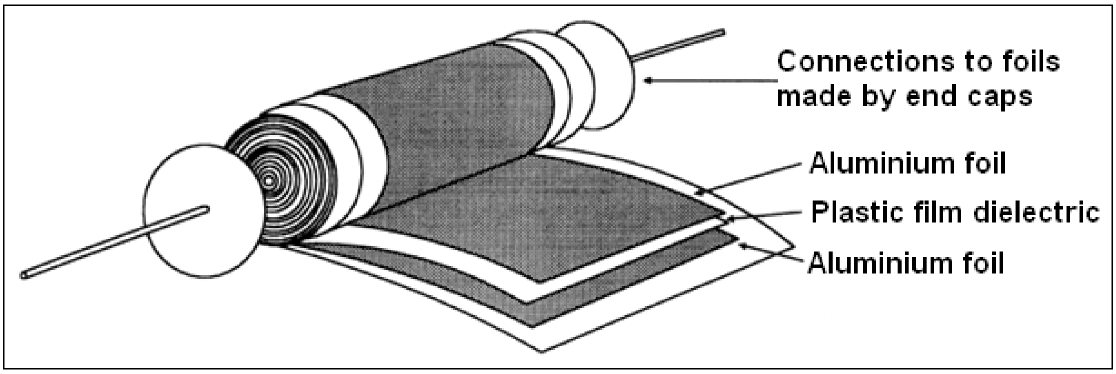


Fig. 2.2-2 Construction of a Typical Tubular Polystyrene Capacitor

CHARGING AND DISCHARGING CAPACITOR

When the switch is turned to **position 1** (Fig. 2.2-3), the voltage on the supply side of the resistor is **6V** and that on the capacitor side is **0V**. By Ohm's Law, the current through the resistor **R** is **6/10000 = 600 μA**. Charging begins and the voltage across the capacitor (Fig. 2.2-4) rises steeply. The voltage on the supply end of **R** stays at **6V**, but the voltage at its other end is increasing. The voltage difference across **R** is **decreasing**. Ohm's Law still applies, so the current through **R** is decreasing. This means that the rate of charge of **C** is decreasing and the voltage across it rises more slowly.

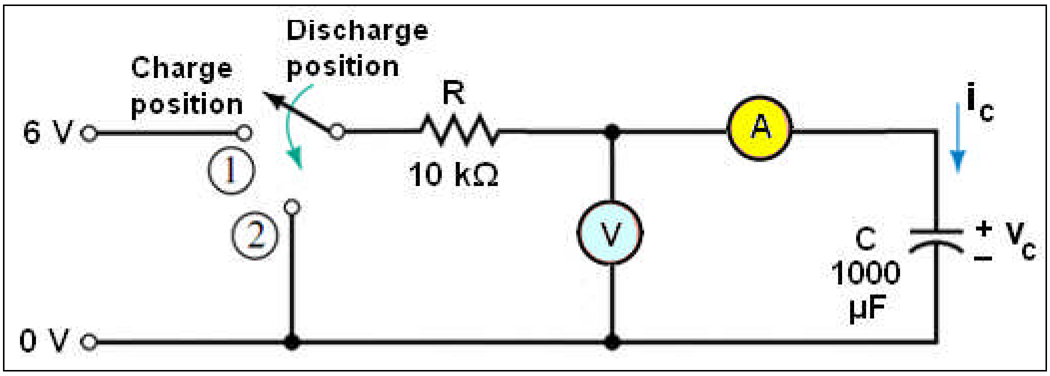


Fig. 2.2-3 Charging and Discharging Capacitor

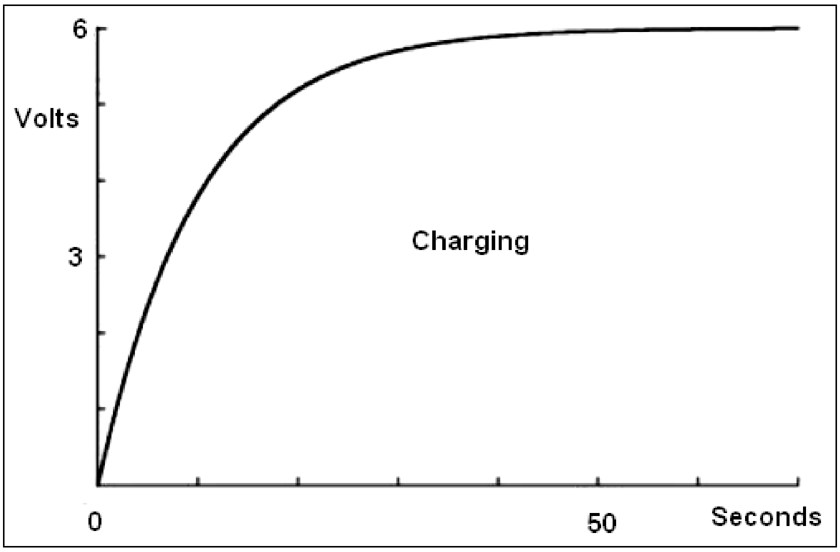


Fig. 2.2-4 Charging Capacitor Curve

The voltage rises more and more slowly until **C** is charged to **6V**. Then there is NO voltage difference across **R** and therefore NO current flows through it. The graph levels out. The capacitor is fully charged.

The reverse happens when the switch is turned to **position 2,** as shown in Fig. 2.2-3, the capacitor is discharged (Fig. 2.2-5). At first, there is a voltage difference of **6V** across **R**, so **600 μA** flows out of the capacitor, through **R** to the **0V** line. The voltage becomes less as the capacitor discharges. The voltage drops more and more slowly. When it reaches **zero**, the capacitor is uncharged.

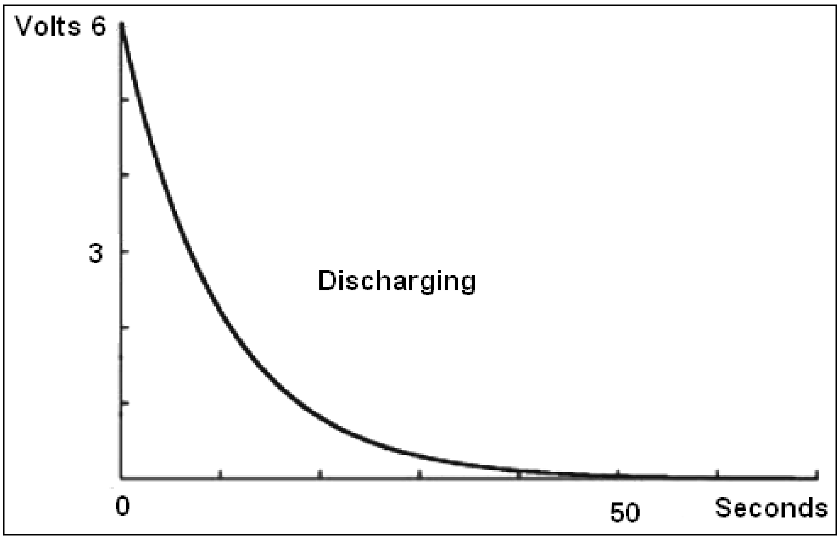


Fig. 2.2-5 Discharging Capacitor Curve

UNIT OF CAPACITANCE

Capacitance is a measure of the amount of charge that a capacitor can store for a given applied voltage. The unit of capacitance is the Farad **(F)**. The Farad is a very large unit and therefore hardly used. Smaller units are:

$$\text{micro-Farad}(\mu F) = \frac{1}{1000000} F = 10^{-6} F$$

$$\text{pico-Farad}(\rho F) = \frac{1}{1000000} \mu F = 10^{-6} \mu F = 10^{-12} F$$

$$\text{nano-Farad}(nF) = \frac{1}{1000} \mu F = 10^{-3} \mu F = 10^{-9} F$$

CAPACITANCE AND VOLTAGE

When a capacitor is charged to a voltage **V**, the charge **Q** is given by **Q = C** x **V** Therefore:

$$C = \frac{Q}{V} \; \& \; V = \frac{Q}{C}$$

Where: **C =** Capacitance (F) **V** = Voltage (V) **Q** =Charge (Coulombs)

ENERGY

The energy stored by a capacitor is given by $W = 1/2\ CV^2$

Where:

W = Energy in joules (J)

C = Capacitance (F)

V = Voltage (V)

FACTORS DETERMINING CAPACITANCE

<table>
<tr>
<td>
Capacitance is determined by three factors (Fig. 2.2-6):
1. Area of capacitor plates (A)
2. Spacing between the plates (d)
3. Nature of the dielectric (ϵ_r)
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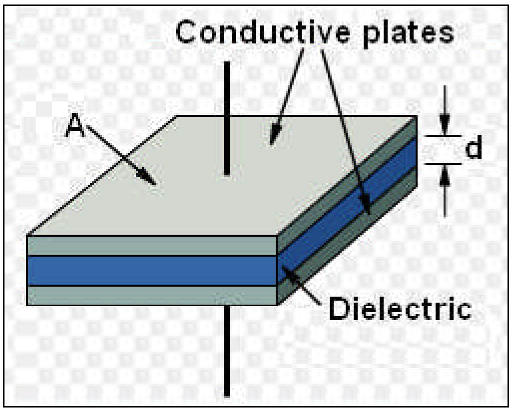

Fig. 2.2-6 Capacitance Factors
</td>
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</table>

The formula that combines the three factors just discussed is:

$$C = \epsilon \left(\frac{A}{d}\right)$$

$$\epsilon = \epsilon_0 \epsilon_r$$

Where:

C = Capacitance in Farads (F)

ϵ = absolute dielectric constant of the insulating material in Farads/meter (F/m)

ϵ_0 = absolute dielectric constant for air = constant = 8.85×10^{-12} in Farads/meter (F/m)

ϵ_r = relative dielectric constant or relative permittivity (Table 2.2-1)

A = Area of the plate in Square meters (m^2)

d = Distance between the two plates in meter (m)

From the above observations, we see that capacitance is **directly** proportional to plate area, **inversely** proportional to plate separation, and **dependent** on the dielectric (**ϵ_r**)

Typical dielectric constants for common types of insulators are given in Table 2.2-1

Material	**Relative Dielectric Constant ϵ_r**
Vacuum	1
Air	1.0006
Ceramic	30-7500
Mica	5.5
Paper (dry)	2.2

Table 2.2-1 Relative Dielectric Constant

EXAMPLE 2.2-1

Compute the capacitance of a parallel-plate capacitor with plates 10 cm by 20 cm, separation of 5 mm, and

a. - an air dielectric.

b. - a ceramic dielectric with permittivity of 7500.

SOLUTION

Convert all dimensions to meters

Thus, A = (0.1 m) (0.2 m) = 0.02 m^2 d = 5 X 10^{-3} m.

a. - For air, ϵ_r = 1 (Table 2.2-1)

$$C = \epsilon_0 \, \epsilon_r \, (\frac{A}{d}) = 8.85 \times 10^{-12} \times 1 \times \frac{2 \times 10^{-2}}{5 \times 10^{-3}}$$

$$= 35.4 \times 10^{-12} \text{ F} = 35.4 \text{ pF}$$

b. - For ceramic, ϵ_r = 7500 (Table 2.2-1)

$$C = \epsilon_0 \, \epsilon_r \, (\frac{A}{d}) = 8.85 \times 10^{-12} \times 7500 \times \frac{2 \times 10^{-2}}{5 \times 10^{-3}}$$

$$= 7500 \times 35.4 \times 10^{-12} \text{ F}$$

$$= 7500 \times 35.4 \text{ pF} = 0.266 \ \mu\text{F}$$

TYPES OF CAPACITORS

Capacitors are available in many different shapes and sizes. However, all capacitors can be placed in one of two categories: Variable and Fixed.

VARIABLE CAPACITORS

Fig. 2.2-7 shows the construction of an air-spaced variable capacitor. As the shaft is turned, the rotating plates change position in relation to the stationary plates.

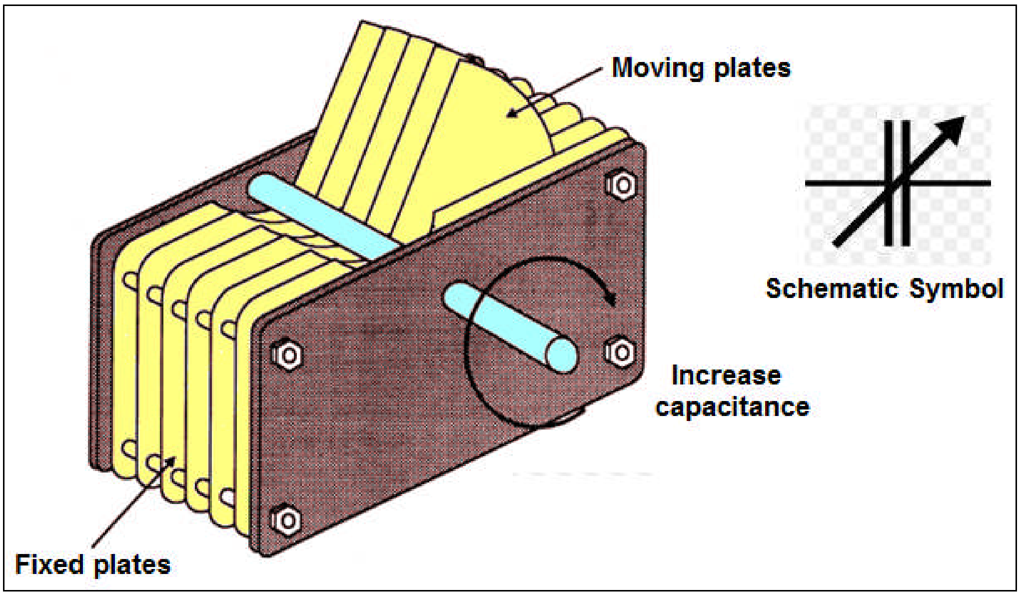


Fig. 2.2-7 Construction of an Air-Spaced Variable Capacitor

By moving the shaft, the area of the plates across from each other can be changed from maximum when fully meshed to minimum when fully open.

FIXED CAPACITORS

Capacitors (Fig. 2.2-8) are often named for the material used as their dielectric (paper, ceramic, mica). Sometimes capacitors are classified according to their shape. Thus, there are disc capacitors and tubular capacitors.

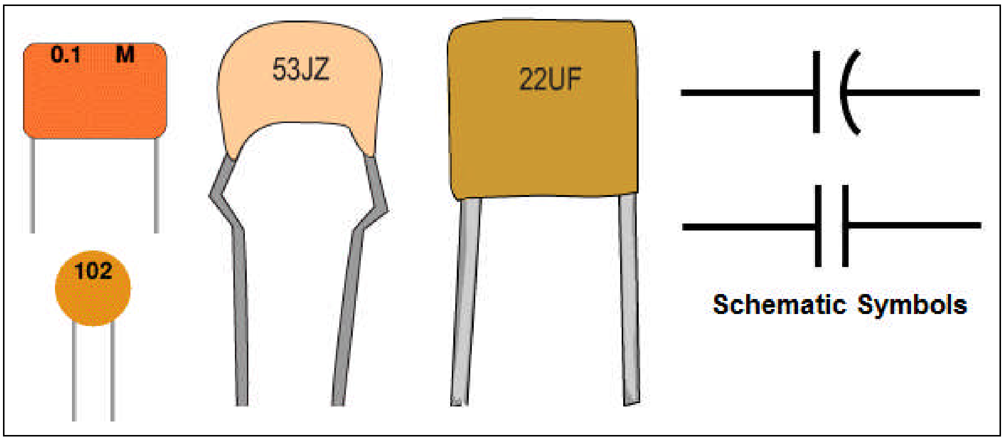


Fig. 2.2-8 Fixed Capacitors

One of the most popular types of fixed capacitor is the **electrolytic capacitor** (Fig. 2.2-9)**,** they are polarized and **they must be connected the correct way round,** at least one of their leads will be marked + or -. If an electrolytic capacitor is connected with its polarity reversed, it may explode.

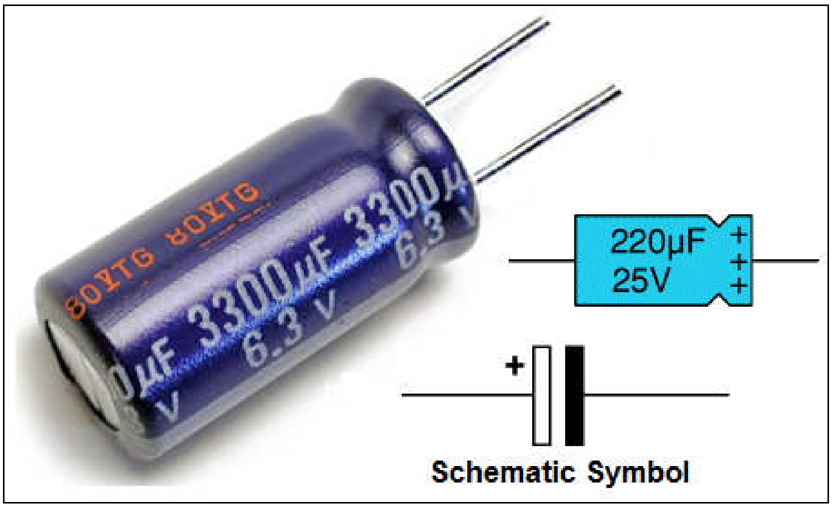


Fig. 2.2-9 Electrolytic Capacitor

TIME CONSTANT

There are two factors that determine the charge or discharge time for a capacitor. These are the **value of capacitance and the value of resistance through** which the capacitor must charge or discharge. A time constant is the time required for a capacitor to charge to 63.2% of the applied voltage.

The time constant can be expressed as:

T = R C.

Where: **T =** time constant (seconds)

R = Resistance (Ω)

C = Capacitance (F)

Some examples may help illustrate this.

If C = 1 μF and R = 100 Ω; then:

T=R x C =100 Ω x 1 μF = 100 μs

If C = 1 μF and R = 10 kΩ; then:

T=R x C =10000 Ω x 1 μF = 10 ms

If C = 1 μF and R = 2 MΩ; then:

T=R x C = 2x 10^6 Ω x 1 μF = 2 s

Fig. 2.2-10 and Fig. 2.2-11 show two curves that are helpful when working with time constants. Fig. 2.2-10 shows how a capacitor charges. For most purposes, the capacitor is considered fully charged after five time constants.

Fig. 2.2-11 shows the capacitor being discharged. After five time constants, the capacitor can be considered as discharged.

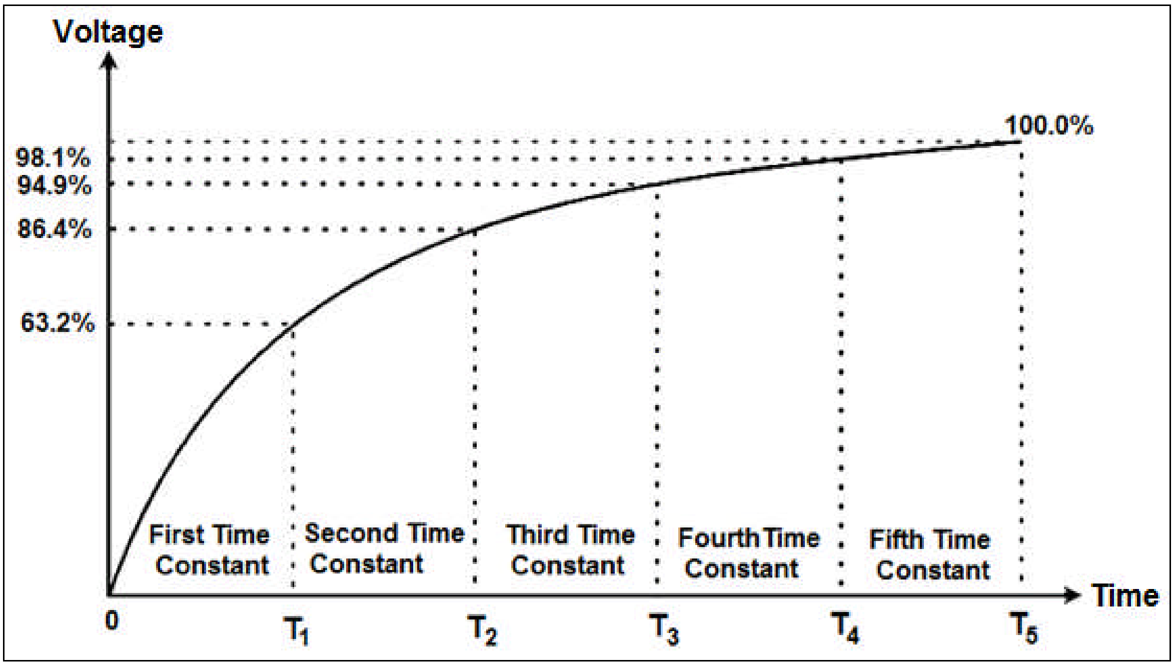


Fig. 2.2-10 Time Constant Curves (Capacitor Charging)

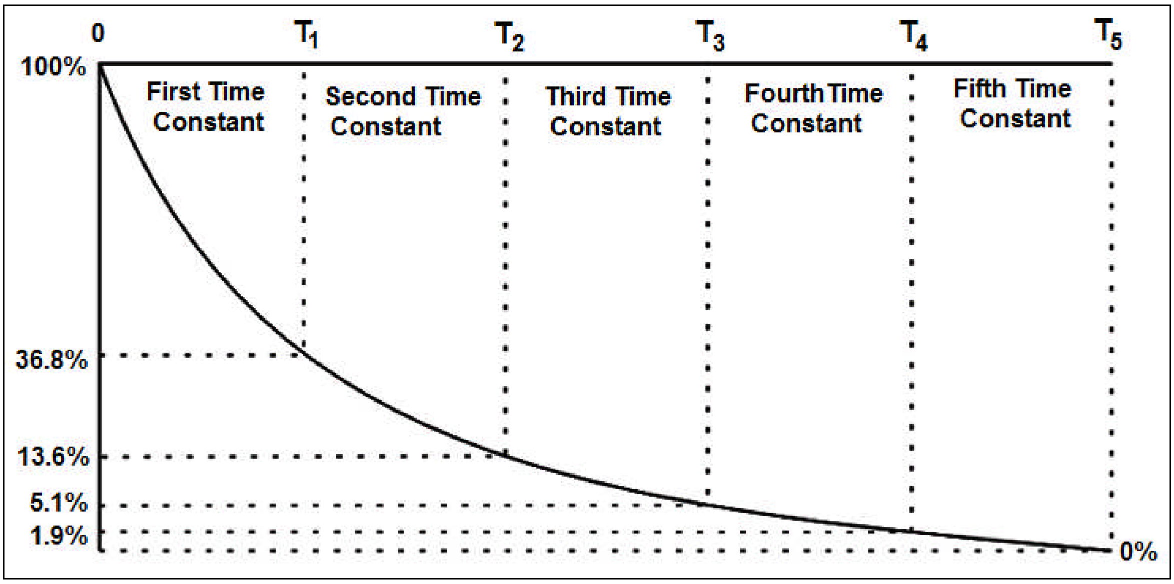


Fig. 2.2-11 Time Constant Curves (Capacitor Discharging)

CAPACITORS IN SERIES AND PARALLEL

Combined capacitance (C) of capacitors connected in series and parallel (Fig. 2.2-12).

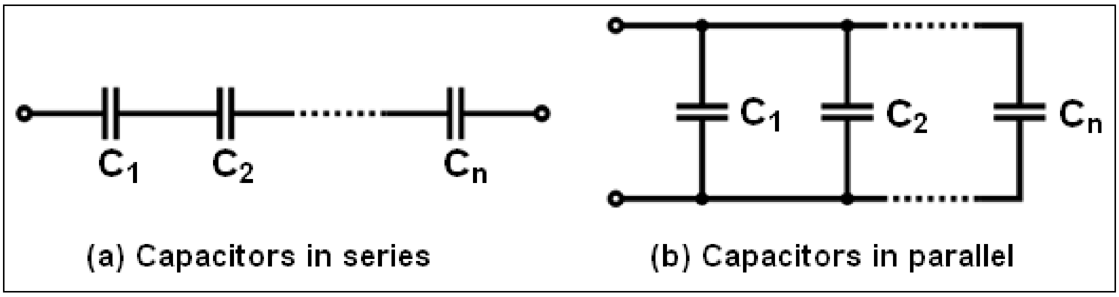


Fig. 2.2-12 Capacitors in Series and Parallel

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_3} + \ldots\ldots \frac{1}{C_n}$$ Capacitors in Series

$$\mathbf{C = C_1 + C_2 + \ldots\ldots\ldots C_n}$$ Capacitors in Parallel

Capacitors in series and in parallel are equivalent to resistors in parallel and in series, respectively.

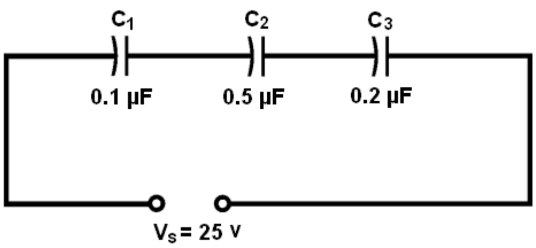
EXAMPLE 2.2-2

Suppose three capacitors are in parallel, having values of C_1= 0.100 μF, C_2 = 0.0100 μF, and C_3 = 0.001000 μF. What is the total capacitance?

SOLUTION

$C = C_1 + C_2 + C_3$

$= 0.1 + 0.01 + 0.001 = 0.111\ \mu F$

EXAMPLE 2.2-3 Find the voltage across each capacitor in Fig. 2.2-13	 Fig. 2.2-13 Example 2.2-3

SOLUTION

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_3} = \frac{1}{0.1\mu F} + \frac{1}{0.5\mu F} + \frac{1}{0.2\mu F}$$

$$C_T = \frac{1}{17}\ \mu F = 0.0588\ \mu F$$

$V_1 = (C_T / C_1)\ V_T = (0.0588\ \mu F / 0.1\ \mu F) \times 25\ V = 14.71\ V$

$V_2 = (C_T / C_2)\ V_T = (0.0588\ \mu F / 0.5\ \mu F) \times 25\ V = 2.94\ V$

$V_3 = (C_T / C_3)\ V_T = (0.0588\ \mu F / 0.2\ \mu F) \times 25\ V = 7.35\ V$

CAPACITORS IN AC CIRCUITS

CAPACITIVE REACTANCE

Capacitance also opposes AC current flow. **Capacitive reactance** is designated by the symbol $\mathbf{X_C}$.The larger the capacitor, the smaller the capacitive reactance. Current flow in a capacitive AC circuit is also dependent on frequency.

The following formula is used to calculate capacitive reactance:

$$\mathbf{X_C = \frac{1}{\omega C} = \frac{1}{2\pi f C} = \frac{0.159}{f C}}$$

Where:

X_C = capacitive reactance in Ohms

ω = angular velocity in radians per second

C = capacitance in farads

f = frequency in hertz

EXAMPLE 2.2-4

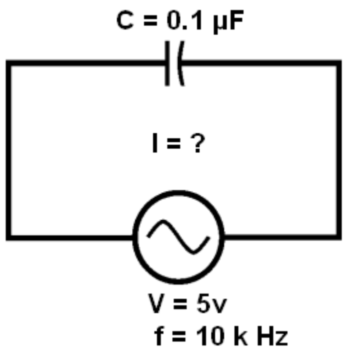
Calculated the capacitive reactance for a 60 hertz circuit with a 10 microfarad capacitor?

SOLUTION

$$X_C = \ = \frac{1}{2\pi f C} = \frac{0.159}{60 \mathrm{X} 0.00001} = 265.39\ \Omega$$

EXAMPLE 2.2-5

Using Ohm's law in capacitive circuits $\mathbf{V = I\ X_C}$, determine the rms current in the Fig. 2.2-14 below.

SOLUTION $X_C = (1 / 2\pi\ f\ C)$ $X_C = 1 / 2\pi\ (10 x\ 10^3\ Hz)(\ 0.1\ x\ 10^{-6}\ F)$ $X_C = 1/2\pi\ (10 x\ 10^3\ Hz)(\ 0.1\ x\ 10^{-6}\ F)$ $= 159\ \Omega$ $I_{rms} = (V_{rms} / X_C) = 0.0314\ A = 31.4\ mA$	 Fig. 2.2-14 Example 2.2-5

POWER IN CAPACITOR

A charged capacitor stores energy in the electric field within the dielectric. An ideal capacitor **does not** dissipate energy; it not only stores it. When an AC voltage is applied to a capacitor, energy is stored by the capacitor during a portion of the voltage cycle then the stored energy is **returned to the source** during another portion of the cycle. **There is no net energy** loss. Fig. 2.2-15 shows the power curve resulting from capacitor voltage and current.

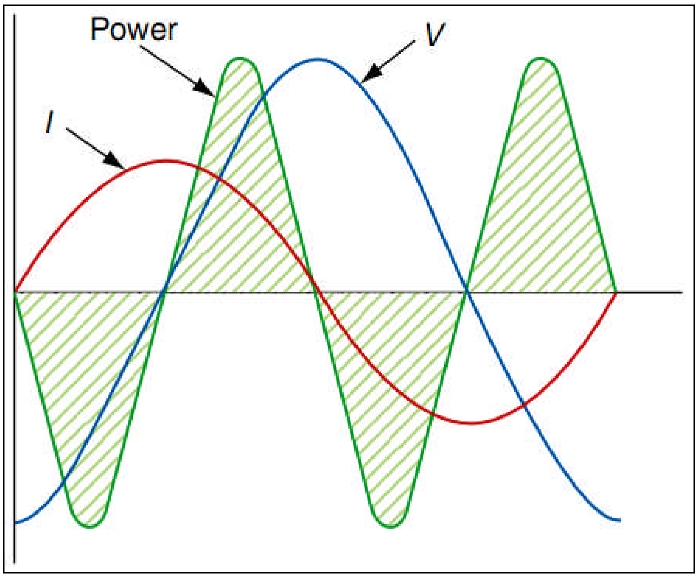


Fig. 2.2-15 Power Curve for Pure Capacitor

INSTANTANEOUS POWER (P_{INST})

The product of **V** and **I** gives instantaneous power, $\mathbf{P_{inst}}$. At points where **V** or **I** is zero, $\mathbf{P_{inst}}$ is also zero. When both **V** and **I** are positive, $\mathbf{P_{inst}}$ is also positive. When either **V** or **I** is positive and the other is negative, $\mathbf{P_{inst}}$ is negative. When both **V** and **I** are negative, $\mathbf{P_{inst}}$ is positive. As you can see, the power follows a sinusoidal curve. Positive values of power indicate that energy is stored by the capacitor. Negative values of power indicate that energy is returned from the capacitor to the source. Note that the power fluctuates at a frequency twice that of the voltage or current as energy is alternately stored and returned to the source.

REACTIVE POWER (Q)

The rate at which capacitor stores or returns energy is called its reactive power **Q**. The reactive power is a none zero quantity, because at any instant in time, the capacitor is actually taking energy from the source or returning energy to it. Reactive power does not represent an energy loss. The following formulas apply:

$$Q = \frac{(V_{rms})^2}{X_C} = I^2_{rms} \times X_C$$

Notice that these equations are of the same form as those for true power in a resistor. The voltage and current are expressed in rms. The unit of reactive power is Volt-Amperes Reactive (**Var**).

CAPACITOR TESTING

Some basic (out-of-circuit) tests can be made with an analog ohmmeter. The ohmmeter can detect opens and shorts and, to a certain extent, leaky dielectrics. First, ensure that the capacitor is discharged, and then set the ohmmeter to its highest range and connect it to the capacitor. (For electrolytic devices, ensure that the plus (+) side of the ohmmeter is connected to the plus (+) side of the capacitor.)

Faulty capacitors respond differently. If a capacitor is shorted, the meter resistance reading will stay low. If it is leaky, the reading will be lower than normal. If it is open circuited, the meter will indicate infinity immediately first connected.

Ohmmeter testing of capacitors has its limitations. Fig. 2.2-16 shows **capacitor tester** can measure capacitance and display it directly on its readout.

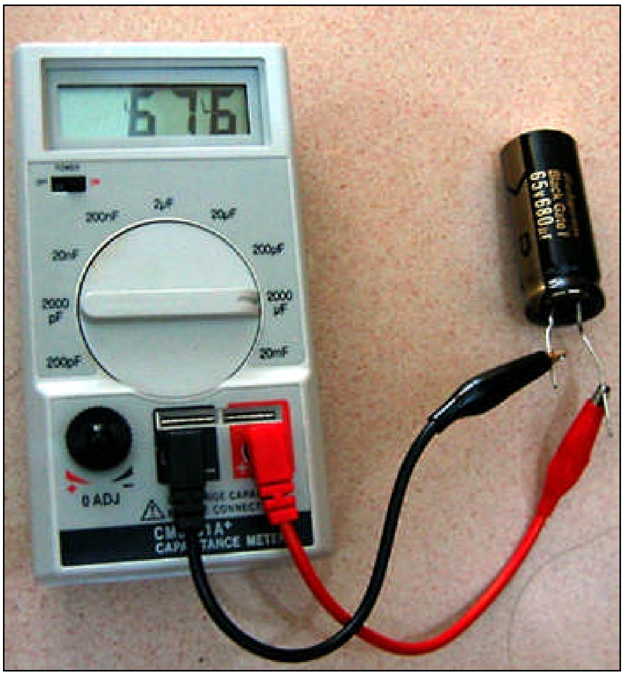


Fig. 2.2-16 Capacitor Tester

RC CIRCUITS

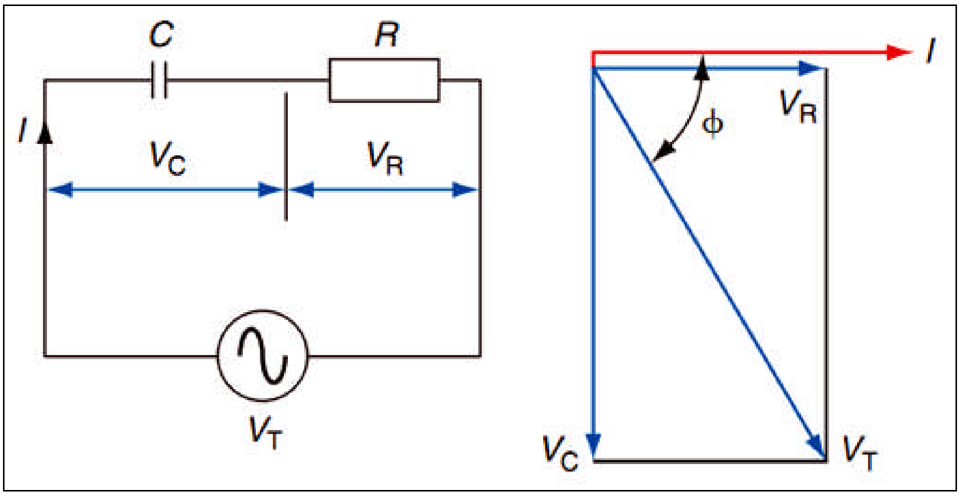


Fig. 2.2-17 a Series RC Circuit and Pharos Diagram

In series RC circuit connected to A.C. voltage (Fig.2.2-17) the following occur:

a. - Current in series circuit is same throughout and used as reference.

b. Voltage across resistor (V_R) is in phase with current.

c. Voltage across capacitor (V_C) lags the current by 90º.

Applied voltage (V_T) is vector sum of the two out-of-phase voltages and equals:

$$V_T = \sqrt{(V_R)^2 + (V_C)^2}$$

Dividing each term of the equation in D by current (Ohm's law.) gives impedance formula:

$$Z = \sqrt{(R)^2 + (X_C)^2}$$

Phase angle θ is expressed as

Tan θ = (X_C / R) **θ = arctan (X_C / R)**

EXAMPLE 2.2-6

If the current in the Fig. 2.2-18 below is 0.2 mA, determine the source voltage and the phase angle.

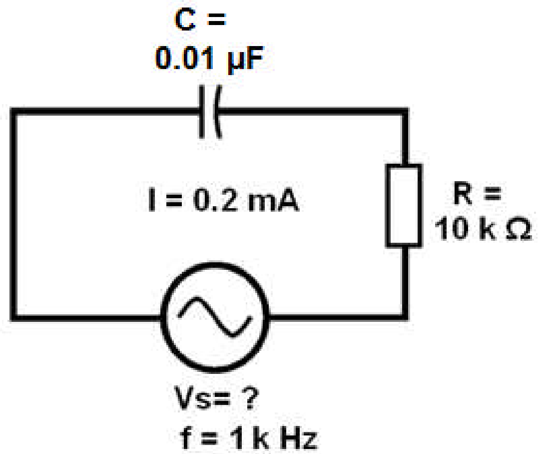


Fig. 2.2-18 Example 2.2-6

SOLUTION

$X_C = 1 / (2\pi fC)$

$=1/ (2\pi)(1x10^3 \text{ Hz}) (0.01x10^{-6} \text{ F})$

$= 15.9 \text{ k}\,\Omega$

$$Z = \sqrt{(R)^2 + (X_C)^2} = \sqrt{(10k\Omega)^2 + (15.9k\,\Omega)^2} = 18.78 \text{ kW}$$

Applying Ohm's law, we obtain

$E_S = I\,Z = (0.2 \text{ mA}) (18.78 \text{ k}\Omega) = 3.76 \text{ V}$

The phase angle is:

$\theta = \arctan (X_C / R) = \arctan (15.9 \text{ k}\Omega / 10\text{k}\Omega) = 57.83°$

PARALLEL RC CIRCUITS

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<td>
A basic parallel RC circuit (Fig. 2.2-19) The expression for the impedance is:

$$Z = \frac{R \times X_C}{\sqrt{(R)^2 + (X_C)^2}}$$

The phase angle between the applied voltage and the total current is $\theta = \arctan(R / X_C)$
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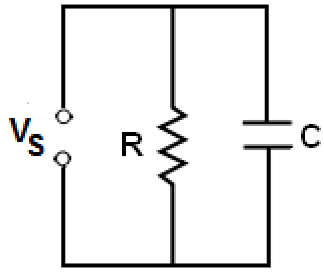

Fig. 2.2-19 Parallel RC Circuit
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EXAMPLE 2.2-7

For the circuit in the Fig. 2.2-19, R = 100 Ω and X_C = 50 Ω. Determine the impedance and the phase angle?

SOLUTION

$Z = RX_C / \sqrt{(R)^2 + (X_C)^2}$

$= (100\ \Omega)\ (50\ \Omega) / \sqrt{(100\Omega)^2 + (50\Omega)^2}$

$= 44.72\ \Omega$

$\theta = \arctan(R / X_C) = \arctan(100\Omega) / 50\Omega) = 63.43°$

NOTE

At parallel circuit the voltage across R equals the voltage across C but the current is divided at the junction into two branches.

POWER IN RC CIRCUIT

The formulas for power in a resistor, sometimes called true power (**P**) and the power in a capacitor, called Reactive Power (**Q**). The unit of true power is the **Watt** (**W**) and that of reactive power is the **Volt-Ampere Reactive** (**VAR**):

$$\mathbf{P = I^2\,R} \qquad\qquad \mathbf{Q = I^2\,X_C}$$

CAPACITORS IN DC CIRCUITS

In DC f = 0 (zero) hence Reactance is '**infinite**' i.e. **1/0**. It means that Capacitor **Opposes** DC Current Flow through it, but **allows** AC through It. In DC the capacitor acts as an **open circuit.**

SUMMARY

- Capacitance impedes the flow of AC charge carriers by temporarily storing the energy as an electric field.
- A device especially designed to have a certain value of capacitance is called a Capacitor that has the ability to store electrons and release them at a later time.
- Capacitance is a measure of the amount of charge that a capacitor can store for a given applied voltage.
- The unit of capacitance is the Farad (F). The Farad is a very large unit and therefore hardly used. Smaller units.
- Capacitance is directly proportional to the area of the plates. As the plate area increases, the capacitance also increases.
- Capacitance is inversely proportional to the spacing between the plates. As the space between the plates decreases, the capacitance increases.
- The capacitance can be greatly increased by changing the dielectric.

- Capacitors are available in many different shapes and sizes. However, all capacitors can be placed in one of two categories: Variable and Fixed.
- Sometimes capacitors are classified according to their shape. Thus, there are disc capacitors and tubular capacitors.
- One of the most popular types of fixed capacitor is the electrolytic capacitor.
- A time constant is the time required for a capacitor to charge to 63.2% of the applied voltage.
- An ideal capacitor does not dissipate energy; it not only stores it.

FORMULA

$$\frac{1}{\mathbf{C_T}} = \frac{1}{\mathbf{C}_1} + \frac{1}{\mathbf{C}_2} + \frac{1}{\mathbf{C}_3} + \ldots\ldots\ldots\ldots + \frac{1}{\mathbf{C_n}}$$ Series Capacitors

$$\mathbf{C_T} = \frac{1}{\left(\frac{1}{\mathbf{C}_1}\right) + \left(\frac{1}{\mathbf{C}_2}\right) + \left(\frac{1}{\mathbf{C}_3}\right) + \ldots\ldots\ldots + \left(\frac{1}{\mathbf{C_n}}\right)}$$ Series Capacitors

$C_T = C_1 + C_2 + C_3 + \ldots + C_n$ Parallel Capacitors

$T = RC$ Time constant

GLOSSARY

Capacitor	A device, which introduces capacitance into an electric circuit
Dielectric	The insulating material between the plates of a capacitor
Farad	The unit of capacitance
Dielectric Constant	The relative ability of an insulator to concentrate electric flux
Capacitance	The measure of a capacitor's ability to store charge.
One Farad	The amount of capacitance when one coulomb of charge is stored with one volt across the plates
Time Constant	The capacitance multiplied by the resistance. The time required for a capacitor to charge or discharge by 63%
Dissipate	Energy to be lost through its conversion into heat

REVIEW EXERCISE

1. (a) Find the capacitance when Q = 50 μC and V = 10 V.

   (b) Find the charge when C = 0.001 μF and V = 1 kV.

   (c) Find the voltage when Q = 2 mC and C = 200 μF.

2. Convert the following values from micro-Farads to pico-Farads:

   (a) 0.1μF

   (b) 0.0025 μF

   (c) 5 μF

3. Convert the following values from pico-Farads to micro-Farads:

   (a) 1000 pF

   (b) 3500 pF

   (c) 250 pF

4. Convert the following values from Farads to micro-Farads:

   (a) 0.0000001 F

   (b) 0.0022 F

   (c) 0.0000000015 F

5. Five 1000 pF capacitors are in series. What is the total capacitance?

6. Determine the time constant for each of the following series RC combination:

   (a) R = 100 Ω, C = lμF   (b) R = 10 MΩ, C = 50 pF

   (c) R = 4.7 kΩ, C = 0.005 μF   (d) R = 1.5 MΩ, C = 0.01 μF

7. Determine how long it takes the capacitor to reach full charge for each of the following RC combinations:

   (a) R = 50 Ω, C = 50 μF   (b) R = 3300 Ω, C = 0.015 μF

   (c) R = 22 kΩ, C = 100 pF   (d) R = 5 MΩ, C = 10 pF

8. A sinusoidal voltage of 20 V_{rms} produces rms current of 100 mA when connected to a certain capacitor. What is the reactance?

TASK 2.2-1

CAPACITOR CHARGE AND DISCHARGE

OBJECTIVES

Upon completion of this task, the trainees will be able to:

- Determine experimentally how a capacitor charges and discharges through a resistor.

MATERIAL/EQUIPMENT

- (1) ET-3100 Electronic Design experimenter or equivalent
- (1) VOM with test leads
- (1) 470 μ F, 15 volt elect. capacitor
- (1) 47 μ F, 15 volt elect. capacitor
- (1) Clock or watch with a sweep second hand
- (1) DPDT slide switch (60-2)
- (1) 100 Ω, 1/2 watt resistor
- (1) 100 kΩ potentiometer (Internal)

PROCEDURE

1. Using the Ohmmeter adjust the 100 K Ohm potentiometer to read exactly 40K Ohms between points 1 & 2, (Fig. 1-1).
2. Without disturbing the setting of the potentiometer, construct the circuit (Fig. 1-1).

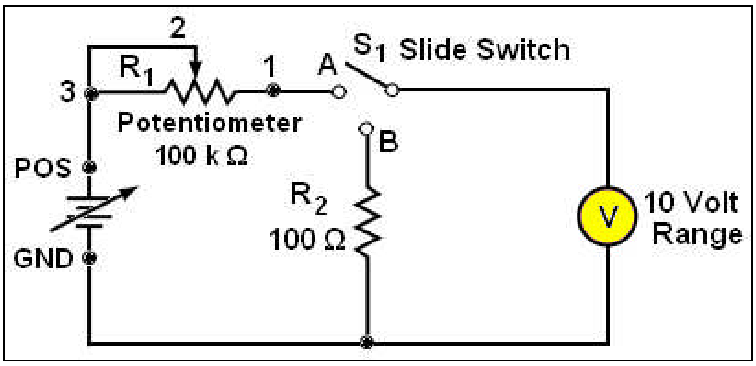


Fig. 1-1 Step 1&2

3. Adjust + voltage control until the voltmeter reads exactly 10 volts.
4. Add the capacitor to the circuit observing carefully its polarity (Fig. 1-2)

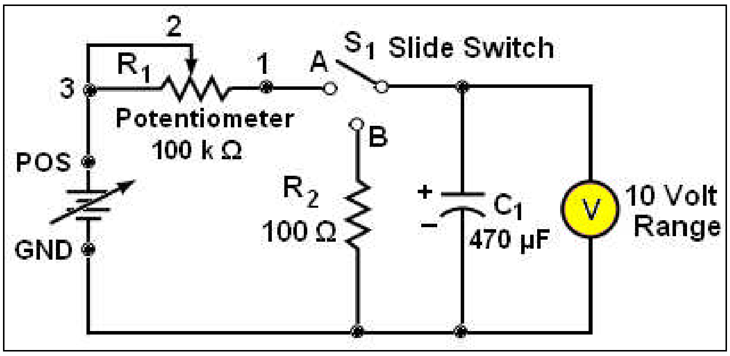


Fig. 1-2 Step 4

5. Place the switch in position B (Fig. 1-2). The voltmeter should now read 0 volts.
   Why? ____
6. Compute the RC time constant. **T = ___________ seconds**
7. plot the voltage you would expect to find across C_1 after charging for intervals of 0, 1, 2, 3, 4 and 5 time constants.

Time Constant	0	1	2	3	4	5
Voltage, V_C	0.0 V					

Tables 1 Capacitor Voltage versus Time Constants

8. Connect these points to form the RC time constant charge curve
9. Place the slide switch in position A and measure the length of time required for the voltage across C1 to charge to 6.32 volts. To get an accurate reading, you may have to repeat this step several times and average the readings together. Be sure to discharge C1 through R2 by setting the slide switch to position B each time you repeat this step. The measured RC time constant is:
   T = _________ seconds
10. Discharge C1 through R2 by placing S1 in position B. Switch S1 to position A and record the voltage across C1 at intervals of 0, 1, 2, 3, 4 and 5 time constants. Record these values in the table shown in Table 1. Be sure that you discharge the capacitor through R2 before each measurement is made.

11. Plot these values on the graph. Connect the plotted points to form the time constant curve.
12. Compare curve plotted in **Step 11** with the curve plotted in **Step 8**.
13. Replace the 470 μF capacitor with the 47 μF capacitor.

    Compute the new circuit time constant. **T = ___________ seconds**
14. Measure the length of the RC time constant using the technique described in **Step** 9. The time constant is now **T = ___________ seconds**

    Does this agree with the computed time constant for the new RC combination?

    ____________________ Yes/No

    What happens to the length of time constant when the value of capacitance decreased? **(Increased/decreased)**
15. Replace the 47 μF capacitor with the 470 μF capacitor. The circuit should now be in the original condition shown in Fig. 1-2.
16. Rotate the shaft of the potentiometer counterclockwise (CCW) one quarter turn. This results in the value of RI: **(increasing/decreasing)**
17. Determine the effect that this has on the RC time constant: **(Increases/Decreases)**
18. Rotate the shaft of the potentiometer fully clockwise (CW). This results in R1: **(Increases/Decreases)**
19. Determine the effect that this has on the RC time constant:

    (Increases/Decreases)
20. Remove power from the circuit in Fig. 1-2. Connect the Ohmmeter between pins 1 and 2 of the 100K Ohm potentiometer. Adjust the potentiometer until the Ohmmeter reads exactly 20K Ohms.
21. Without disturbing the setting of the 100 K Ohm potentiometer, construct the circuit shown in Fig. 1-3. Be sure to observe polarity when connecting the 470-microfarad capacitor.
22. Place S1 in position A and allow C1 to charge through R2. Adjust the positive voltage control until the voltage across the capacitor is exactly 10 volts.
23. If the switch is placed in position B, C1 will discharge through R1. Compute the RC time constant. The time constant is: **T = ______________ seconds**

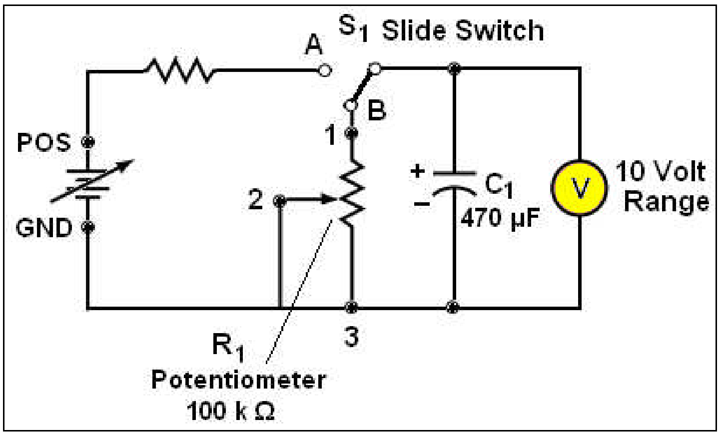


Fig. 1-3 Circuit for Plotting the Discharge Curve

24. Plot the voltage you would expect to find across C, after discharging for intervals of 0, 1, 2, 3, 4 and 5 time constants.
25. Connect these points to form the RC time constant discharge curve.
26. When C1 is fully charged, switch S1 to position B so that C1 discharges through R1. Measure the time required for C1 to discharge to 3.68 volts.

    The measured RC time constant is: **T = __________ seconds**.

    How does this compare with the value computed in Step 22?
27. Measure the voltage across C1 after discharging for intervals of 0, 1, 2, 3, 4 and 5 time constants. Record the values in Table 2.

Time Constant	0	1	2	3	4	5
Voltage, V_C	0.0 V					

Tables 2 Capacitor Voltage versus Time Constants

28. Connect the plotted points to form the time constant discharge curve.
29. Compare the curve plotted in **Step 27** with the curve plotted in **Step 24**.

    Vary the value of R_1 and verify that the time constant is directly proportional to the value of R_1. Charge and discharge the capacitor each time you change R_1 and measure the time constant.

TASK 2.2-2

CAPACITORS IN SERIES AND PARALLEL

OBJECTIVES

Upon completion of this task, the trainees will be able to:

- Demonstrate how voltage is distributed between series capacitors.
- Demonstrate how total capacitance is affected by connecting capacitors in series and parallel.

MATERIAL/EQUIPMENT

- (1) ET-3100 Electronic Design Experimenter or equivalent
- (1) VOM with test leads
- (1) 470 µ F,15 volt electrolytic capacitor (25-157)
- (1) 47 µ F,15 volt electrolytic capacitor (25-98)
- Clock or watch with a sweep second hand
- (1) DPDT slide switch (60-2)
- (1) 100 Ω, 1/2 watt resistor (brown-black-brown-gold)
- (1) 100 kΩ potentiometer (built into ET-3100)

PROCEDURE

1. Adjust the positive voltage for a reading of 10 volts between the positive and ground terminals.
2. Construct the circuit shown in Fig. 2-1.
3. Measure the voltage across each capacitor.
4. Record the measured values below:

   Voltage across 47 µF capacitor = __________ volts

   Voltage across 470 µF capacitor = __________ volts

   Is the sum of the two voltages equal to the applied voltage? __________ (Yes/No)

5. Which capacitor charges to the higher voltage? __________ (larger/smaller)

   Repeat the experiment with the 470 μF and the 10 μF capacitor connected in series.

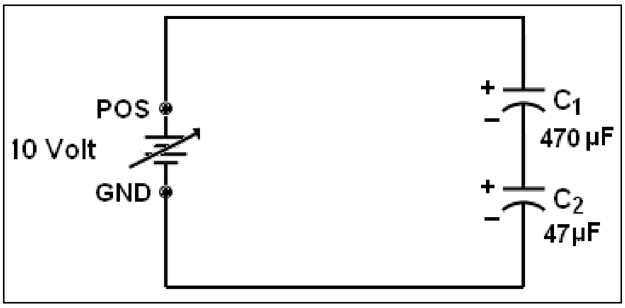


Fig. 2-1 Step 2

6. Disconnect the circuit in Fig. 2-2 and construct the circuit shown in Fig. 2-2(a). Place switch S_1 in position A. Turn the shaft of the 100 K Ω potentiometer fully-clockwise. Adjust the + voltage control until the meter reads exactly 10 volts.
7. Add the 470-μF capacitor to the circuit (Fig. 2-2(b). Switch S1 to position B so that C1 can completely discharge.

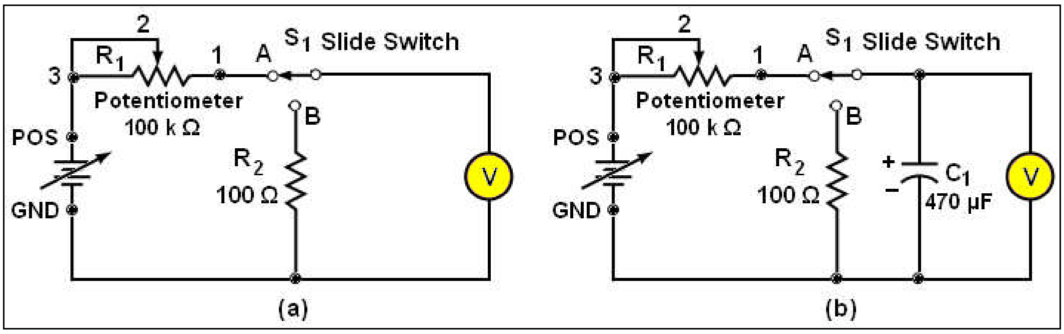


Fig. 2-2 Step 6 and 7

8. Set switch S_1 to position A. The voltage across C_1 reaches 6.32 volts after one time constant. **(T = _____________ seconds)**
9. Now connect the 47 μ F capacitor (C_2) in series with C_1 (Fig. 2-3). Switch S1 to the B position so that the capacitors completely discharge.
10. Switch S1 back to position A and measure the time required for C_1 and C_2 in series to charge to 6.32 volts. **The time is: (___________ seconds)**

11. What has happened to the length of the time constant? (Increased/decreased) Why? ____

What assumption can we make concerning capacitors in series? _____________

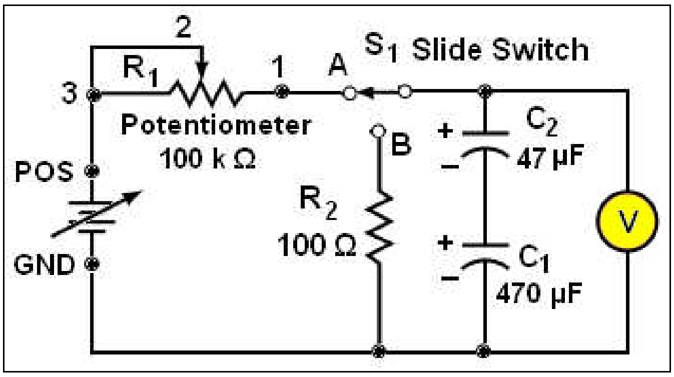


Fig. 2-3 Capacitors in Series

12. Construct the circuit shown in Fig. 2-4.

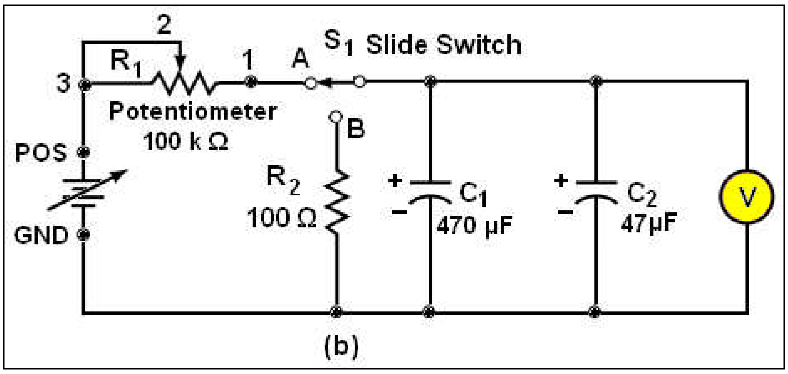


Fig. 2-4 Capacitors in Parallel

13. Repeat **Step 8** several times, carefully noting the length the time constant. Be sure to completely discharge C1 before each measurement. The measured time constant is: **(T = _______________ seconds)**

14. Add the 47µF capacitor (C_2) in parallel with C_1, (Fig. 2-4). Once again carefully measure the RC time constant. The time constant is:

(T = ____________ seconds)

15. What has happened to the length of the time constant? (Increased/Decreased) Why? ____

What assumption can we make concerning capacitors in parallel?

____

TASK 2.2-3

CAPACITOR APPLICATIONS

OBJECTIVES

Upon completion of this task, the trainees will be able to:

- Demonstrate some of the ways that capacitors are used.

MATERIAL/EQUIPMENT

- (1) ET-3100 Electronic Design Experimenter or equivalent
- (1) VOM with test leads
- (1) 470 μ F,15 volt electrolytic capacitor (25-157)
- (1) 47 μ F,15 volt electrolytic capacitor (25-98)
- (1) DPDT slide switch (60-2)
- (1) Lamp (412-16)
- (1) Clock or watch with a sweep second hand
- (1) 100 Ω, 2 watt resistor (brown-black-brown-gold)
- (1) 100 kΩ potentiometer (built into ET-3100)
- (1) Lamp socket (434-21)
- (1) Relay (69-50)

PROCEDURE

1. Connect the circuit shown in Fig. 3-1. Adjust the positive voltage so that the voltage between the positive and ground terminals is 8 volts.
2. Switch S1 back and forth between positions A and B. Does the lamp light? ____________________ yes/no

   Does it stay light ____________________ yes/no

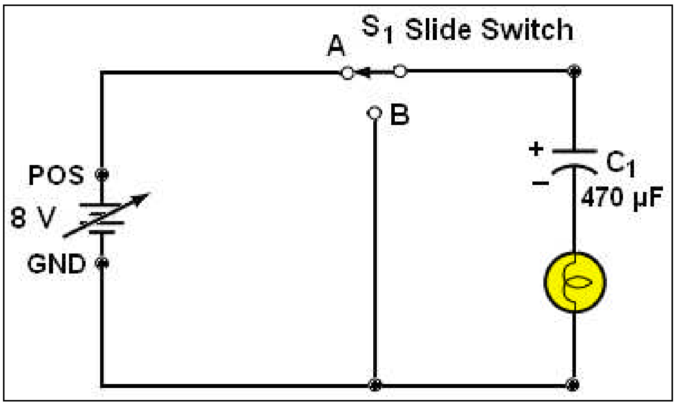


Fig. 3-1 Capacitor Blocks Direct Current

3. Switch S_1 to position A. After the first instant, does any current flow through the lamp? ____________ (yes/no).

   Explain why? ____

4. Construct the circuit shown in Fig. 3-2(a). Close S_1 and adjust the positive voltage until the meter reads exactly 10 volts.

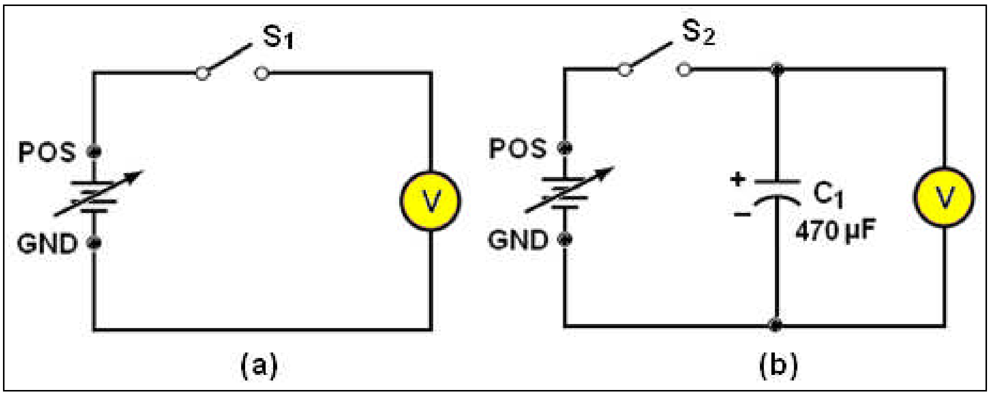


Fig. 3-2 Capacitor Converts Pulsating DC to Direct Current

5. Open and close the switch about once a second and note the action of the meter.
6. Add the 470 µF capacitor (C_1) across the meter, as shown in Fig. 3-2(b).
7. Open and close the switch about once a second and note the action of the meter. Does the meter behave differently than it did in **Step 5**? ___________ (yes/no) Explain the difference if any.

   ____

8. Disconnect the previous circuit. Set the positive voltage to 5 volts.
9. Construct the circuit shown in Fig. 3-3.

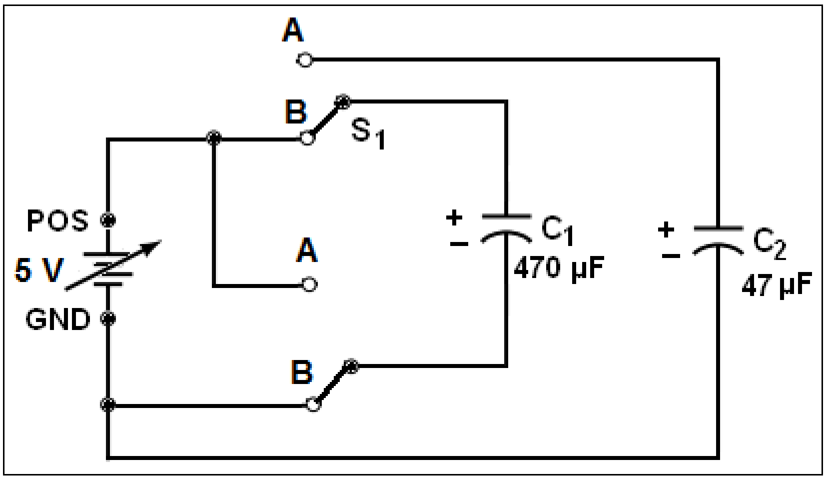


Fig. 3-3 Capacitors Used in Voltage Doublers

10. With S1 set to the B position, measure the voltage across C1.

    The voltage is: (__________________ volts).

11. Next, connect the voltmeter across C2 Switch S1 back and forth between positions A and B several times until the voltage stops rising.

    The voltage across C2 is: (____________ volts)

    How do you account for the fact that the voltage across C_2 is higher than the voltage applied to the circuit?

    ____

    Where did the extra voltage come from?

    ____

12. Disconnect the previous circuit. Turn the positive voltage control completely counterclockwise (minimum voltage).
13. Construct the circuit shown in Fig. 3-4.

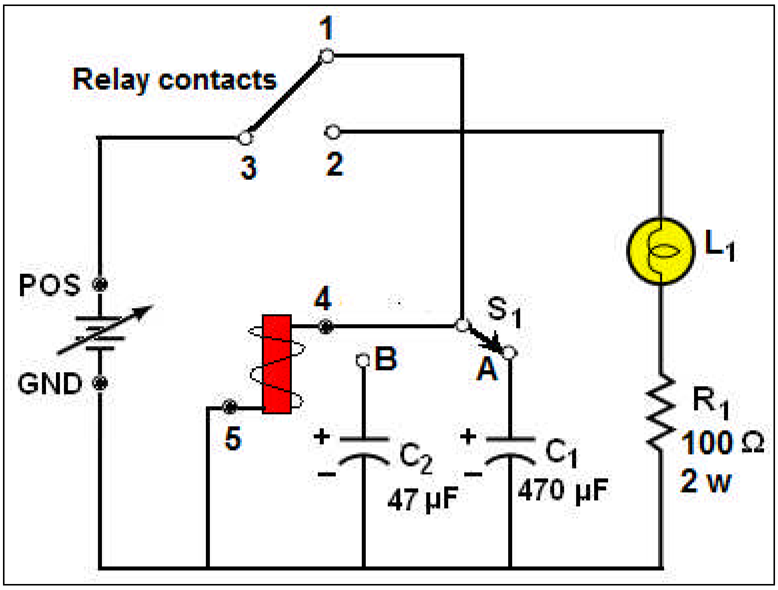
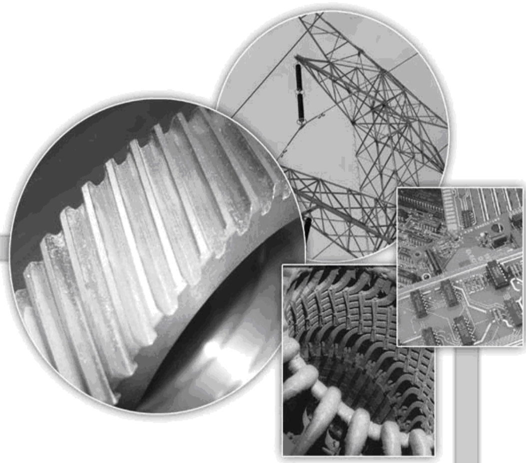


Fig. 3-4 Capacitors Used for Timing

14. Place the slide switch (S_1) in position A so that C_1 is connected in parallel with the relay coil.
15. Slowly adjust the positive voltage until the relay energizes causing L_1 to light. Continue to increase the voltage slowly until the lamp blinks on and off at a regular rate. Do not increase the voltage beyond this point.
16. To demonstrate C_1 contribution to the circuit, momentarily disconnect one end of C_1 from the circuit.

    What happens to the relay? __________ Energized/de-energized

    Does L_1 continue to blink? _______________ (yes/no).
17. Reconnect C_1 to the circuit and note the rate at which L_1 blinks? ______ seconds.
18. Switch S_1 to position B. What happens to the rate at which L_1 blinks? __________________ increases/decreases.
19. Analyze the schematic diagram of the blinker circuit and determine how it operates.



LESSON 2.3

RESONANTCIRCUITS ANDFILTERS

LESSON 2.3

RESONANT CIRCUITS AND FILTERS

OVERVIEW

This lesson explains the series resonant RLC circuit characteristics and their applications in different types of filters.

OBJECTIVES

Upon completion of this lesson, the trainees will be able to:

- Analyze the conditions for series and parallel resonance.
- Describe the applications of series and parallel **RLC** resonant circuits in different types of filters (Low-Pass, High-Pass).

Task 2.3-1: Series Resonance

INTRODUCTION

The **resonant circuit** consists of an inductor and a capacitor together with a voltage or current source. Although the circuit is simple, it is one of the most important circuits used in electronics. As an example, the resonant circuit, in one of its many forms, allows us to select a desired radio or television signal from the vast number of signals that are around us at any time.

SERIES RLC CIRCUITS

A series RLC circuit (Fig. 2.3-1) contains resistance, inductance and capacitance. As you know, X_L causes the total current to lag the applied voltage, whereas X_C has the opposite effect causing the current to lead the voltage. Thus, X_L and X_C tend to offset each other.

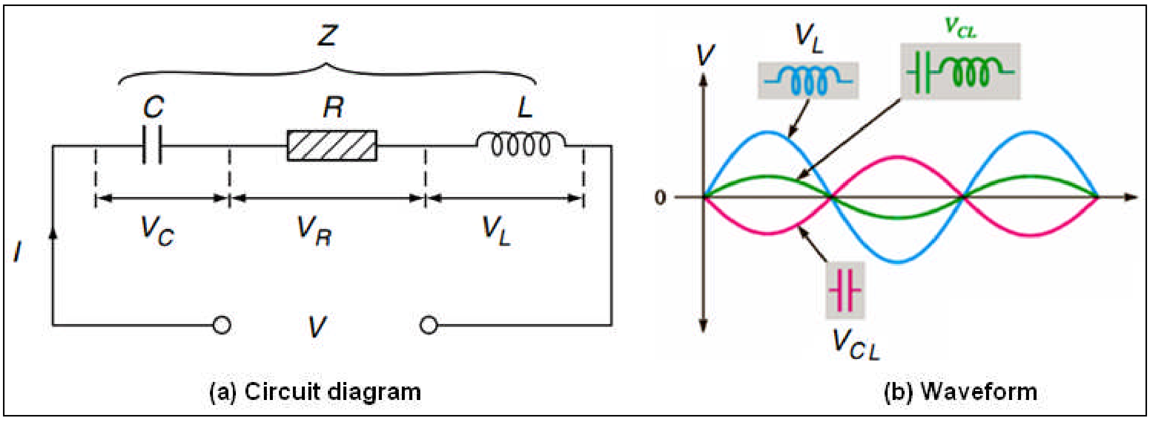


Fig. 2.3-1 Series RLC Circuit

When they are equal, they cancel and the total reactance is zero. In any case, the total reactance in the series circuit is:

$$\mathbf{X_T = (X_L - X_C)}$$

The term ($\mathbf{X_L}$ - $\mathbf{X_C}$) means the absolute value of the difference of the two reactances. When $\mathbf{X_L} > \mathbf{X_C}$, the circuit is inductive and when $\mathbf{X_L} < \mathbf{X_C}$ (Fig. 2.3-2), the circuit is capacitive.

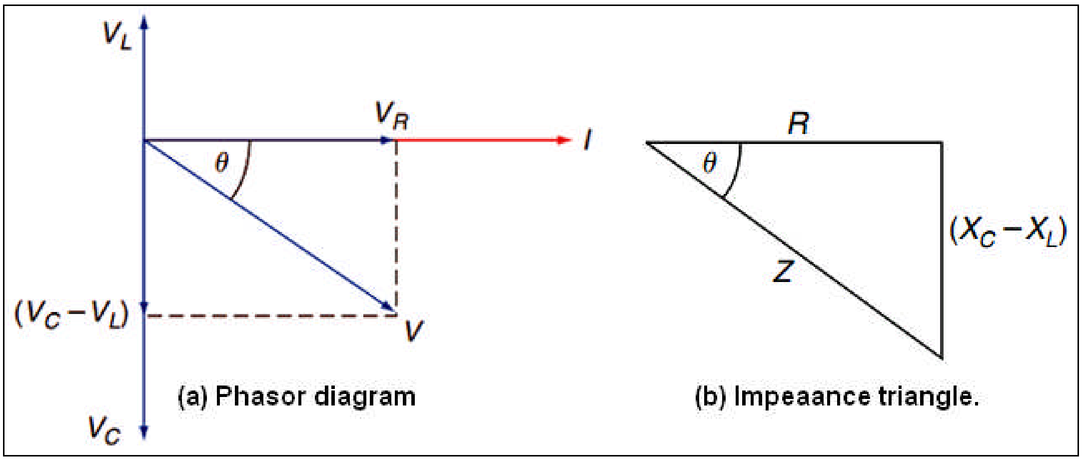


Fig. 2.3-2 Phasor Diagram and Impedance Triangle for Series RLC

The total impedance for the series RLC circuit is given by:

$$\mathbf{Z = \sqrt{R^2 + (X_L - X_C)^2}}$$

The phase angle is: θ = **arctan (X_T / R)**

SERIES RESONANCE

In a series RLC circuit, series resonance occurs when $\mathbf{X_L = X_C}$. The frequency at which resonance occurs is called the **resonant frequency** ($\mathbf{f_r}$). Fig. 2.3-3 illustrates the series resonant condition. Since $\mathbf{X_L = X_C}$, the reactances effectively cancel and the impedance is purely resistive. These resonant conditions are stated in the following equations.

$\mathbf{X_L = X_C}$

$\mathbf{Z_T = R}$

EXAMPLE 2.3-1

For the series **RLC** circuit in Fig. 2.3-1, R = 100 Ω, X_L = 50 Ω determine $\mathbf{X_C}$ and **Z** at resonance

SOLUTION

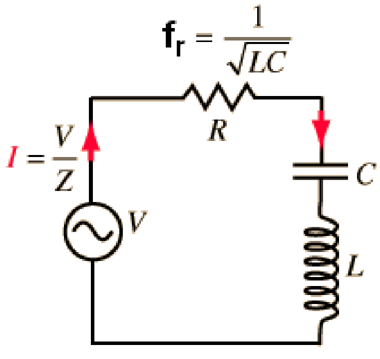
$X_C = X_L = 50\ \Omega$ at resonant

$Z_T = R = 100\ \Omega$ at resonant

SERIES RESONANCE FREQUENCY

For series **RLC** (Fig. 2.3-3) circuit, resonance occurs at only one specific frequency. A formula for this resonant frequency (**f_r**) is developed as follows:

$X_L = X_C$

Substituting the reactance formulas, we have: $2\pi f_r L = \dfrac{1}{2\pi f_r C}$ $f_r = \dfrac{1}{2\pi\sqrt{LC}}$	 Fig. 2.3-3 Series Resonance

The only opposition to the current flow at series resonance is the resistance of the circuit. Thus, in a series resonant circuit, impedance is minimum, consisting only of resistance and current flow is maximum. Relative to the source, the current and voltage are in phase under this condition.

EXAMPLE 2.3-2

For the series **RLC** circuit in Fig. 3.3-3, R = 100 Ω, L = 5 m H, C = 50 pF. Find the series resonant frequency?

SOLUTION

$$f_r = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{(5\times10^{-3}\times50\times10^{-12})}} = 318.3 \text{ kHz}$$

APPLICATIONS OF SERIES RLC CIRCUITS

Series **LC** and **RLC** circuits are used widely as filters and tuned circuits in television, radio, radar, sonar and other electronic communication equipment because of their ability to allow a large current to flow at the resonant frequency (Fig. 2.3-4) while providing a high opposition to current flow at all other frequencies.

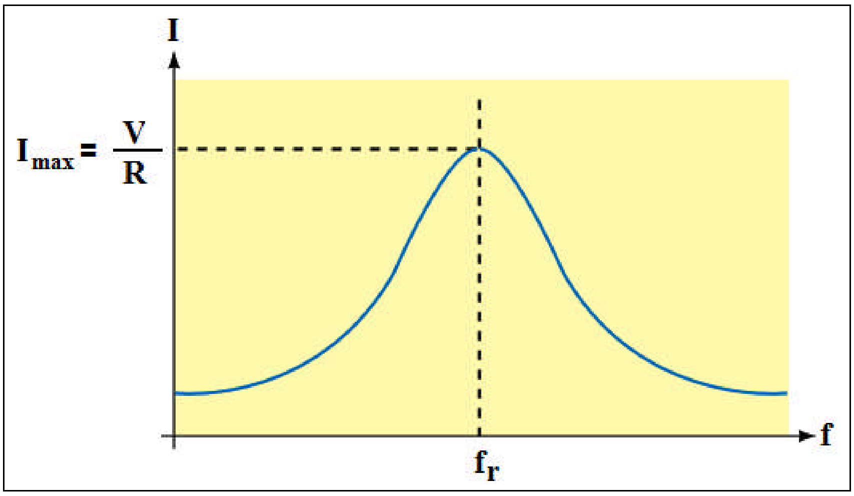


Fig. 2.3-4 Current versus Frequency for a Series Resonant Circuit

<table>
<tr>
<td>EXAMPLE 2.3-3

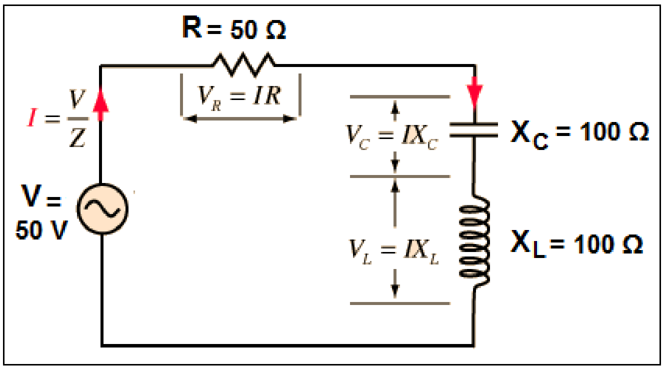
Find I, V$\mathbf{V_R}$, $\mathbf{V_L}$ and $\mathbf{V_C}$ at resonant frequency for the circuit shown in Fig. 2.3-5</td>
<td>

Fig. 2.3-5 Series Resonant Frequency</td>
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SOLUTION

At resonant, current (I) is maximum, $\mathbf{I_{max} = V/R}$

$I = V_S/R = (50\ V)/\ (50\ \Omega) = 1\ A$

Applying Ohm's law, we obtain the following voltages:

$V_R = I\ R = (1\ A)\ (50\ \Omega) = 50\ V$

$V_L = I\ X_L = (1\ A)\ (100\ \Omega) = 100\ V$

$V_C = I\ X_C = (1\ A)\ (100\ \Omega) = 100\ V$

The voltages are maximum at resonance but drop off above and below $\mathbf{f_r}$. The voltages across **L** and **C** at resonance are exactly equal in magnitude but 180° out of phase, so that they cancel and $\mathbf{V_R = V}$. Individually, $\mathbf{V_L}$ and $\mathbf{V_C}$ can be much greater than the source voltage. Keep in mind that $\mathbf{V_L}$ and $\mathbf{V_C}$ are always opposite in polarity regardless of the frequency, but only at resonance their magnitudes are equal.

PARALLEL RESONANCE

When you connect a coil and capacitor in parallel **(**Fig. 2.3-6**)** and apply an AC voltage across them, current in the inductive branch lags the voltage by 90° while current in the capacitive branch leads the voltage by 90°. If the two reactances are unequal, a larger current flows in the branch having the smallest reactance. Since the two currents are 180° out of phase with respect to each other, the net current flow in the circuit is the vector sum or difference between the two branch currents. This net current flow is known as the line current and is the current that flows between the **AC** source and the parallel connected **LC** circuit. The phase of this resultant current with respect to the applied voltage is determined by the larger of the two branch currents. Current flow between the two branches (coil and capacitor) is referred to as circulating current.

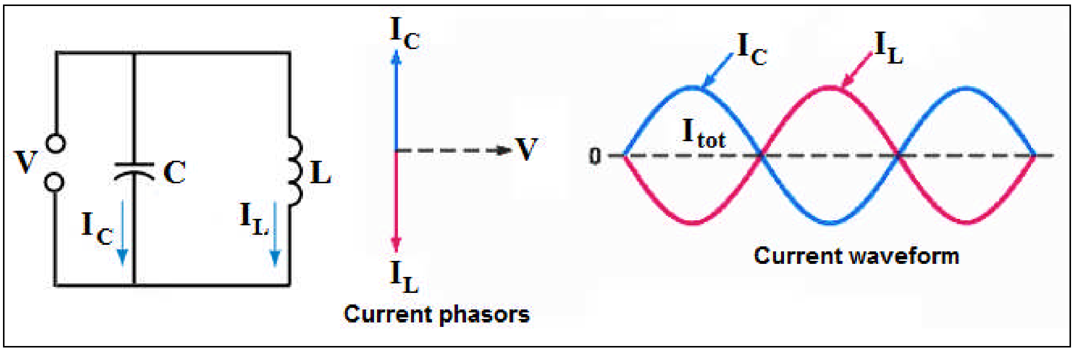


Fig. 2.3-6 an Ideal Parallel LC Circuit at Resonance

If you change the frequency of the voltage applied across the parallel LC circuit to the point where $\mathbf{X_L}$ and $\mathbf{X_C}$ are equal, the two branch currents will be equal. In this case, the branch currents tend to cancel completely, producing minimum line current. To the source then, the parallel **LC** circuit at resonance appears to be a relatively large resistance. This condition is known as parallel resonance. The mathematical formula for calculating the approximate resonant frequency of a parallel resonant circuit is the same as for series resonance:

$$\mathbf{f_r = 1/2\,\pi\,\sqrt{LC}}$$

In summing the current will be minimum **(**Fig. 2.3-7**)**, the impedance peaks to maximum and phase angle zero at parallel resonance.

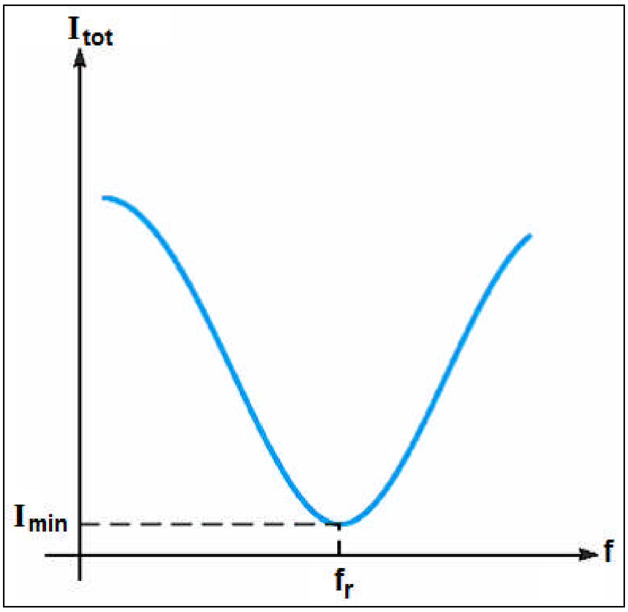
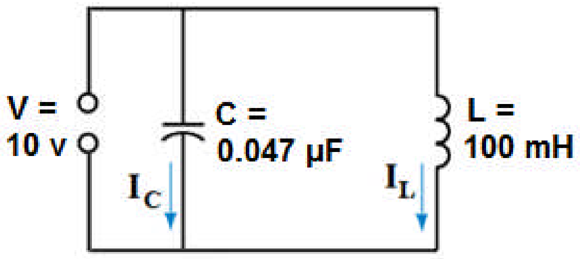


Fig. 2.3-7 Current versus Frequency for a Parallel Resonant Circuit

<table>
<tr>
<td>EXAMPLE 2.3-4

Find the resonant frequency and the branch currents in the ideal parallel LC circuit of Fig. 2.3-8?</td>
<td>Fig. 2.3-8 an Ideal Parallel LC Circuit at Resonance</td>
</tr>
</table>

SOLUTION

$$f_r = \frac{1}{2\,\pi\,\sqrt{LC}} = \frac{1}{2\,\pi\,\sqrt{(100 \text{ X } 10^{-3})\ (0.047 \text{X } 10^{-6})}} = 2322\,\text{Hz} = 2.322\text{ k Hz}$$

$X_L = 2\ \pi\ f\ L = 2\ \pi\ (2322\text{ Hz})\ (100 \times 10^{-3}) = 1459\ \Omega$

$X_C = X_L = 1459\ \Omega$

$I_L = V_S / X_L = (10\text{ V}) / (1459\ \Omega) = 6.85\text{ mA}$

$I_C = I_L = 6.85\text{ mA}$ (I_C opposes I_L)

$I_{LC} = 0\text{ A}$

APPLICATION OF PARALLEL RESONANCE

The practical applications of parallel **LC** and **RLC** circuits are virtually unlimited in electronics. They are used extensively in radio, radar, sonar and communications equipment for passing a selected band of frequencies and rejecting all undesirable frequencies outside the desired bandwidth.

LOW-PASS AND HIGH-PASS FILTER

Low-pass and high-pass filter circuits are able to pass low frequencies and high frequencies, respectively, while blocking other frequency components. A good understanding of these filters provides a basis for understanding why circuits such as

amplifiers and oscilloscopes are not able to pass all signals from their input to their output.

RC LOW-PASS FILTER

A **low-pass RC filter** circuit permits low-frequency signals to pass from the input to the output while attenuating high frequency signals.

The simplest form of low-pass filter is shown in Fig. 2.3-9(a). It consists of a resistor and capacitor connected in series across an input voltage. The output voltage is taken across the capacitor.

Assume that the input voltage $\mathbf{V_{in}}$ is **fixed** but that its frequency can be **varied**. The best way to understand the operation of the low-pass filter is to look at the circuit as a **voltage divider**, as shown in Fig. 2.3-9(b).

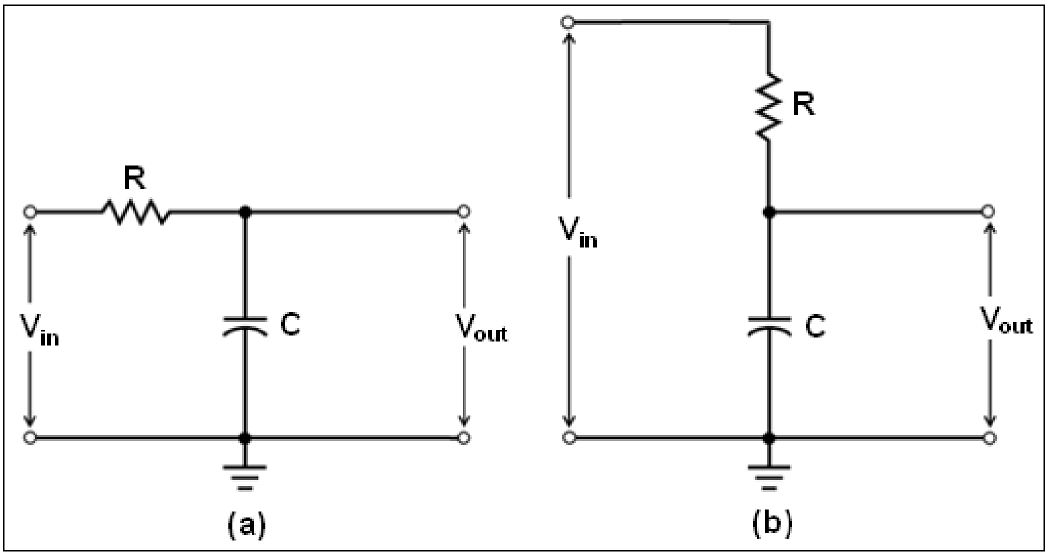


Fig. 2.3-9 RC Low-Pass Filter

Fig. 2.3-10 shows a specific series of measurements for RC Low-Pass Filter in which the frequency starts at zero (DC) and is increased in increments up to 20 kHz. At each frequency point, the output voltage is measured (Table 2.3-1). The capacitive

reactance decreases as frequency goes up, thus dropping less voltage across the capacitor while the input voltage is held at a constant 10 V throughout each step.

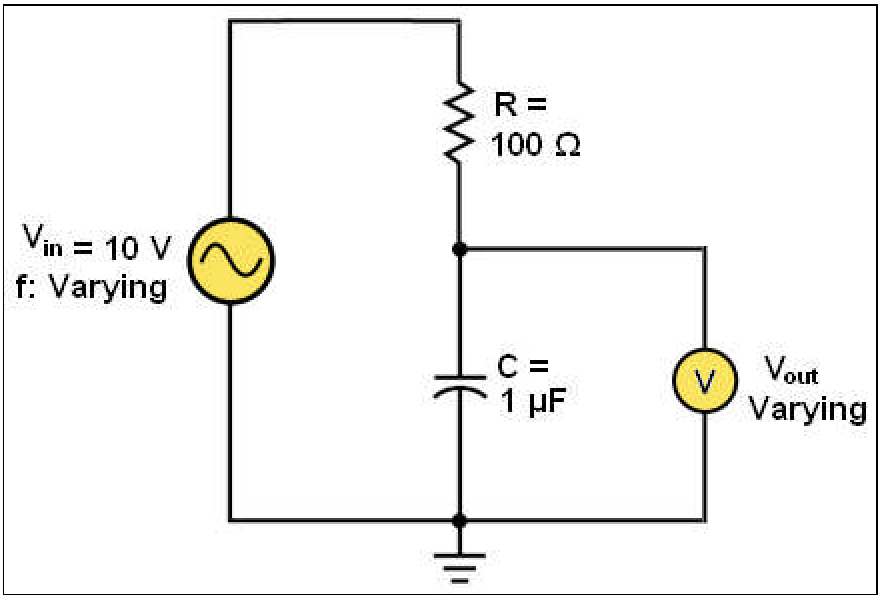


Fig. 2.3-10 Example of RC Low-Pass Filter Action

V_{in} (volt)	f (Hz)	R (Ω)	C (µF)	X_C (Ω)	V_{out} (volt)
10	0	100	1	∞	10
	100			1591.5	9.5
	1000			159.2	6.15
	10000			15.92	1.37
	20000			7.96	0.74

Table 2.3-1 A Specific Series of Measurements for RC Low-Pass Filter

Fig. 2.3-11 shows frequency response curve for RC low-pass filter. We note that at low frequencies, the capacitor has a very large reactance. Consequently, at low frequencies the capacitor is essentially an open circuit resulting in higher voltage across the capacitor, $\mathbf{V_{out}}$ to be essentially equal to the applied voltage $\mathbf{V_{in}}$.

At high frequencies, the capacitor has a very small reactance, which essentially short circuits the output terminals. The voltage at the output will therefore approach zero as the frequency increases

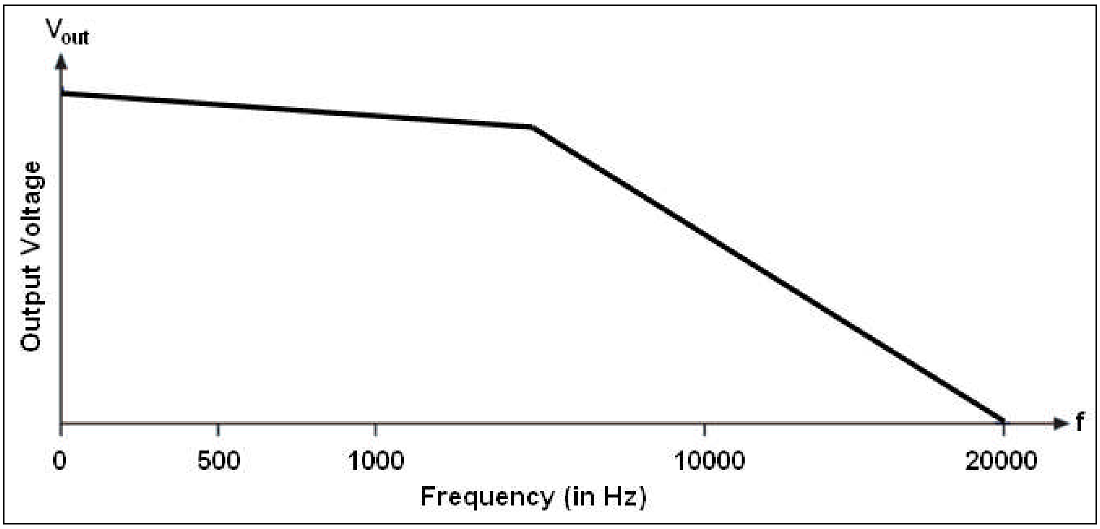


Fig. 2.3-11 Frequency Response of RC Low-Pass Filter

RC HIGH-PASS FILTER

A high-pass filter is a circuit, which allows high-frequency signals to pass from the input to the output of the circuit while attenuating low-frequency signals.

The simplest form of high -pass filter is shown in Fig. 2.3-12(a). It consists of a resistor and capacitor connected in series across an input voltage. The output voltage is taken across the resistor.

Assume that the input voltage $\mathbf{V_{in}}$ is **fixed** but that its frequency can be **varied**. The best way to understand the operation of the high -Pass Filter is to look at the circuit as a voltage divider, as shown in Fig. 2.3-12(b).

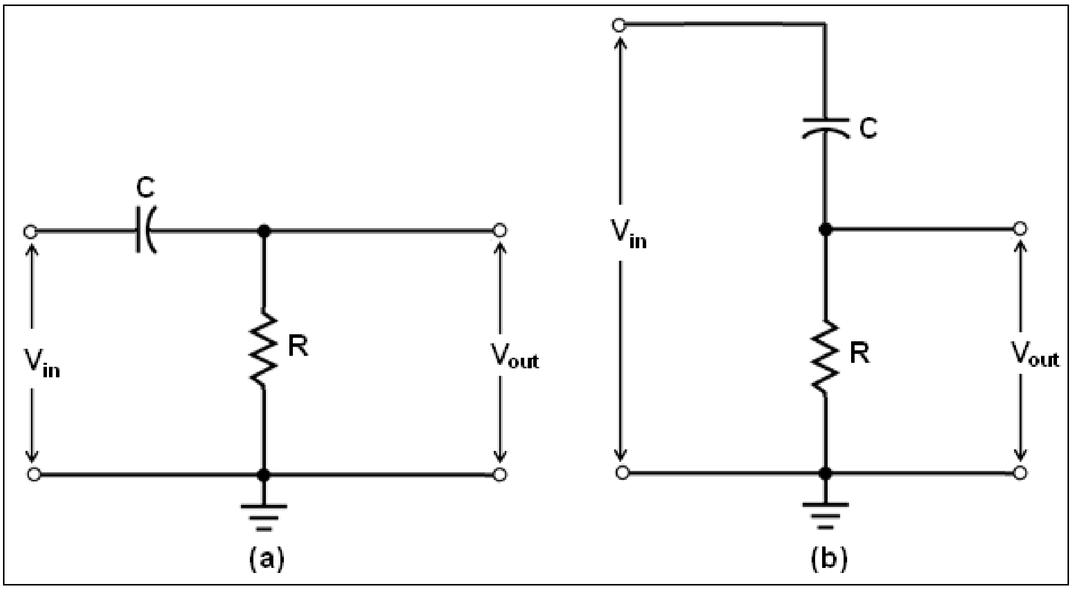


Fig. 2.3-12 RC High-Pass Filter

Fig. 2.3-13 shows a specific series of measurements for RC high-pass filter in which the frequency starts at zero (DC) and is increased in increments up to 10 kHz. At each frequency point, the output voltage is measured (Table 2.3-2). The capacitive reactance decreases as frequency goes up, thus causing more of the total input voltage drop across the resistor.

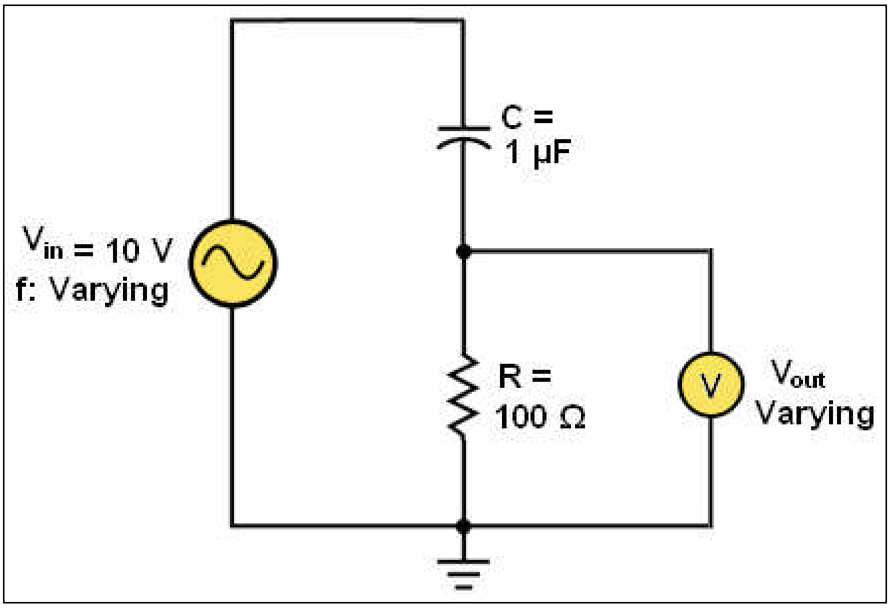


Fig. 2.3-13 Example of RC High-Pass Filter Action

V_{in} (volt)	f (Hz)	R (Ω)	C (μF)	X_C (Ω)	V_{out} (volt)
10	0	100	1	∞	0
	100			1591.5	0.6
	1000			159.2	3.9
	10000			15.9	8.6
	20000			7.96	9.3

Table 2.3-2 A Specific Series of Measurements for RC High-Pass Filter

Fig. 2.3-14 shows frequency response curve for RC high-pass filter.

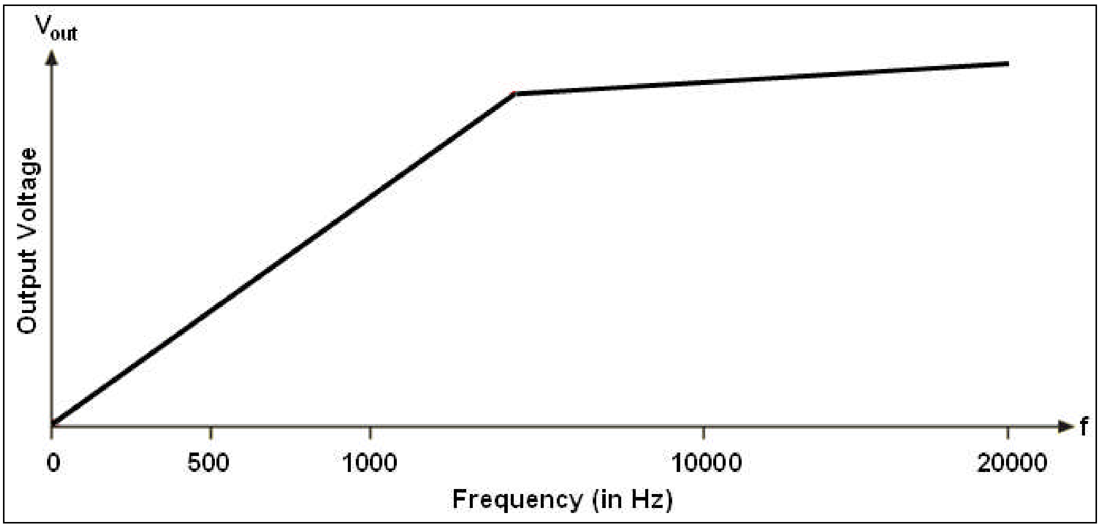


Fig. 2.3-14 Frequency Response of RC High-Pass Filter

We note that (Fig. 2.3-14) at low frequencies, the reactance of the capacitor will be very large, effectively preventing any input signal from passing through to the output. At high frequencies, the capacitive reactance will approach a short-circuit condition, providing a very low impedance path for the signal from the input to the output.

RL LOW-PASS FILTER

Fig. 2.3-15 shows a specific series of measurements for RL low-pass filter in which the frequency starts at zero (DC) and is increased in increments up to 20 kHz. At each value of frequency the output voltage is measured (Table 2.3-3).

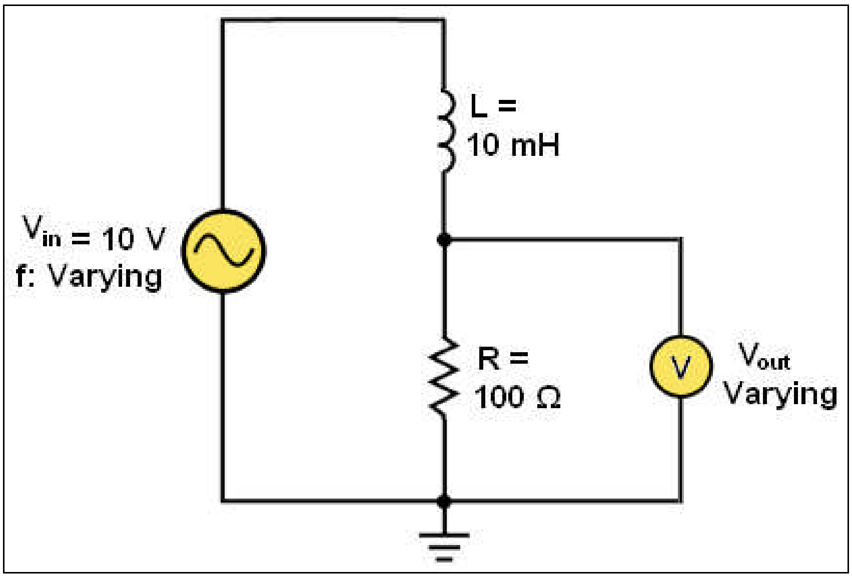


Fig. 2.3-15 Example of Low-Pass Filter Action

V_{in} (volt)	f (Hz)	R (Ω)	L (mH)	X_L (Ω)	V_{out} (volt)
10	0	100	10	0	10
	1000			62.83	6.41
	10000			628.32	1.73
	20000			1256.63	0.737

Table 2.3-3 A Specific Series of Measurements for RL Low-Pass Filter

Table 2.3-3 illustrates the inductive reactance increases as frequency goes up, thus causing less voltage drop across the resistor while the input voltage is held at a constant 10 V throughout each step, assuming winding resistance neglected. The response curve for these particular values would appear the same as the response curve for the **RC low-pass filter** (Fig. 2.3-11).

RL HIGH PASS FILTER

Fig. 2.3-16 shows a series of specific measurements. Again, the frequency starts at zero (DC) and is increased in increments up to 10 KHz. At each value of frequency the output voltage is measured (Table 2.3-4).

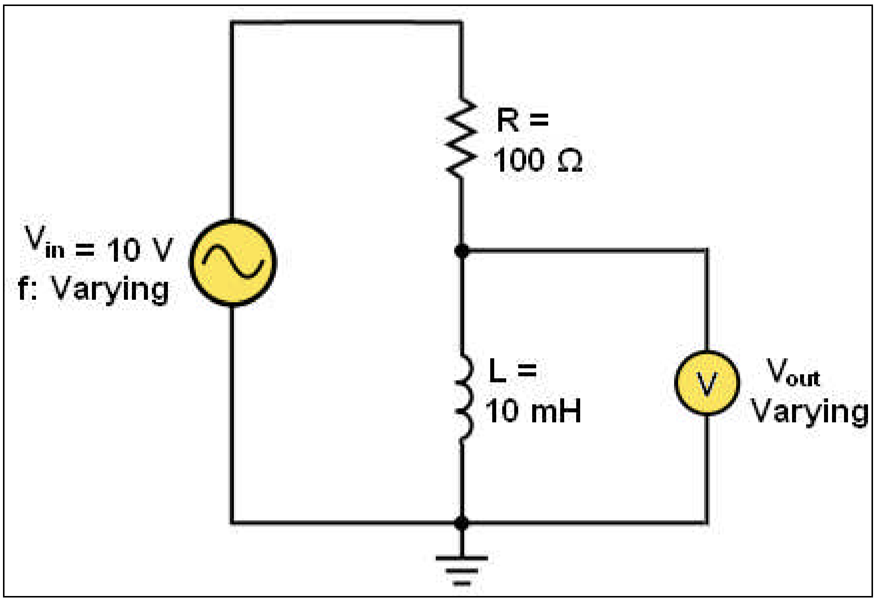


Fig. 2.3-16 Example of High-Pass Filter Action

V_{in} (volt)	f (Hz)	R (Ω)	L (mH)	X_L (Ω)	V_{out} (volt)
10	0	100	10	0	0
	100			6.28	0.6
	1000			62.8	3.86
	10000			628.3	8.6

Table 2.3-4 A Specific Series of Measurements for RL High-Pass Filter

Table 2.3-4 illustrates the inductive reactance increases as the frequency goes up, thus causing more voltage drop across the inductor, assuming winding resistance neglected. Again, when the values are plotted, the response curve is the same as the one for the **RC High-Pass Filter** (Fig. 2.3-14).

CROSSOVER CIRCUIT

More than one loudspeaker is needed to handle the full range of **frequencies**. In practice a large loudspeaker, called a **woofer**, deals with low frequencies while a smaller loudspeaker, called a **tweeter**, deals with high frequencies (Fig. 2.3-17).

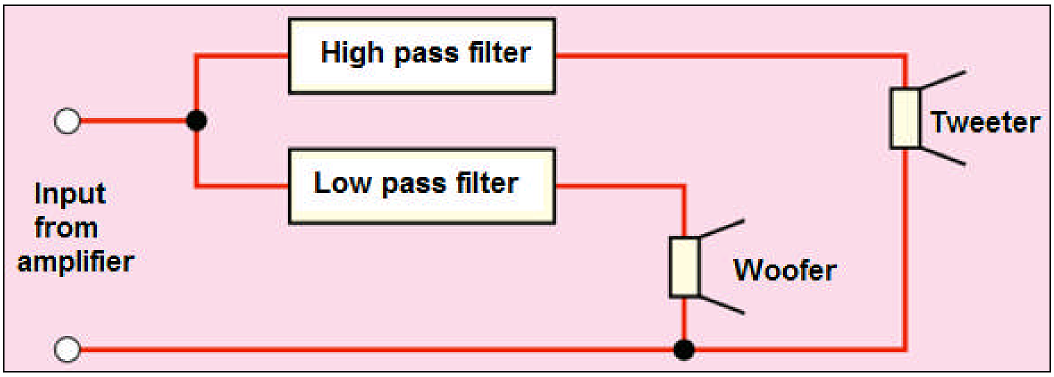


Fig. 2.3-17 Crossover Circuit

The appropriate range of frequencies is directed to each speaker by a crossover circuit. The low pass filter passes low frequencies while blocking high frequencies. The high pass filter has the opposite effect.

A common crossover frequency is 3 kHz. Frequencies above this go mostly to the tweeter while frequencies below this go mostly to the woofer.

SUMMARY

AT SERIES RESONANCE

- The reactances are equal.
- The impedance is minimum and equal to the resistance.
- The current is maximum.
- The phase angle is zero.
- The voltages across L and C are equal in magnitude and 180° out of phase with each other and thus they cancel.

AT PARALLEL RESONANCE

- The impedance is maximum.
- The current is minimum and, ideally, equal to zero.
- The phase angle is zero.

- The currents in the L and C branches are equal in magnitude and 180° out of phase with each other.

FILTERS

- Filters are used in electronics to attenuate or reject unwanted some signal frequencies and pass others.
- Inductors and capacitors are used in filter circuits because they are frequency selective and have very little power loss.
- A capacitor in series with the source attenuates the low frequencies more than the high frequencies; in parallel it develops the low frequency voltages and shunts the high frequencies to ground.

FORMULAS

	Series Resonant Circuit	**Parallel Resonant Circuit**
Impedance	Minimum	Maximum
Current	Maximum	Minimum
Impedance at Resonance	Resistive	Resistive
Impedance below Resonance	Capacitive	Inductive
Impedance above Resonance	Inductive	Capacitive
Impedance Formula	$Z = \sqrt{R^2 + (X_L - X_C)^2}$	$Z = E_A / I_T$

GLOSSARY

Low-pass RC filter	A circuit permits low-frequency signals to pass from the input to the output while attenuating high frequency signals
High-pass filter	A circuit which allows high-frequency signals to pass from the input to the output of the circuit while attenuating low-frequency signals
Woofer	Deals with low frequencies
Tweeter	Deals with high frequencies

REVIEW EXERCISE

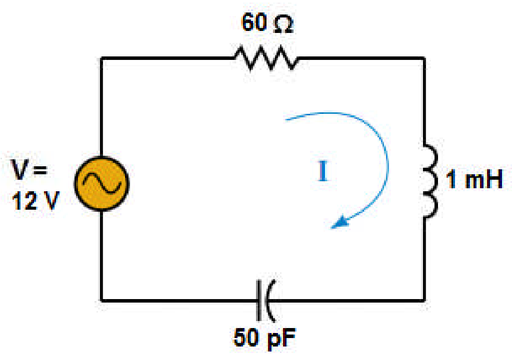
<table>
<tr>
<td>1. For the circuit shown in Fig. 2.3-18, find: X_L, X_C, Z and I at resonance frequency</td>
<td>

Fig. 2.3-18 Series Resonance Circuit</td>
</tr>
</table>

2. For the circuit shown Fig. 2.3-19:
   a. Find the total impedance of the circuit.
   b. Is the circuit capacitive or inductive? Explain.
   c. Find all the currents and voltages

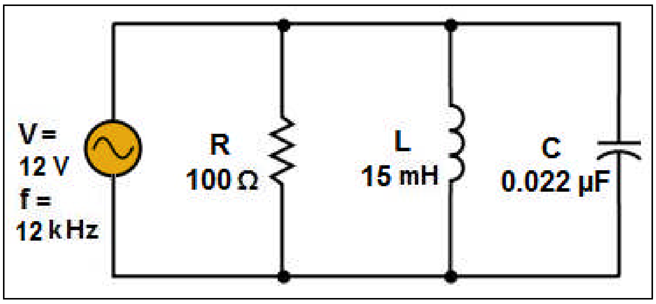


Fig. 2.3-19 Parallel RLC Circuit

Complete by filling in blanks:

3. A high-pass filter is a circuit which ______high-frequency signals to pass from the input to the output of the circuit while attenuating _____-frequency signals.
4. A low-pass filter is a circuit which ______ low-frequency signals to pass from the input to the output of the circuit while attenuating ______-frequency signals.
5. The simplest form of low-pass filter consists of a resistor and capacitor connected in _______across an input voltage. The _____________ is taken across the capacitor.

TASK 2.3-1

SERIES RESONANCE

OBJECTIVES

Upon completion of this task, the trainees will be able to:

- Investigate the characteristics of series resonant circuits.
- Measure the parameters of a series resonant circuit.

MATERIAL/EQUIPMENT

- (1) ET-3100 Electronic Design Experimenter or equivalent
- (1) VOM with test leads
- (1) 107 mH Choke
- (1) 0.001 μF, Ceramic capacitor.
- (1) 0.01 μF, Mylar capacitor.
- (2) 1000 Ω, 1/2 watt resistor

PROCEDURES

1. Turn on the Trainer and **Set** the signal generator **Range Switch** to the **HIGH** position (2 kHz to 20 kHz).
2. Set the voltmeter to a low AC range. Measure the voltage between the GND and SINE terminals of the generator. Slowly turn the frequency knob and notice the average output voltage is nearly constant on all frequencies. The generator output average voltage from 2 kHz to 20 kHz is: (VAC = ______________volts.)
3. Disconnect the voltmeter. Construct the circuit shown in Fig. 1-1.
4. Connect the AC voltmeter across $\mathbf{R_1}$. Adjust the frequency control until the voltage across $\mathbf{R_1}$ is maximum. Record the measurement.

   $E_{R1\,(max)}$ = ______________volts.

   Is this the resonant point? __________________________________

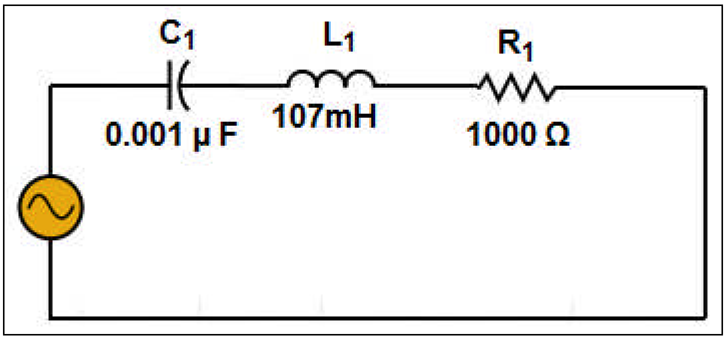


Fig. 1-1

5. Using a pencil, mark the point on the frequency dial at which the maximum voltage across **R_1** occurred. While it is difficult to read the exact frequency from the dial, the resonant frequency is approximately: ______________ Hz.

   With the frequency control set to this frequency, measure the applied AC input voltage between the **SINE** and **GND** terminals. Record the measured value of **E_{IN}**.

   (E_{IN} =__________________ volt)

   Compare this value with the value measured in **Step** 2. Has the voltage changed?

   ____.

6. Using the values of **L_1** and **C_1** given in Fig. 1-1 to compute the resonant frequency of the circuit. (f_o = _____________ Hz)

   Explain how this compares with the frequency you approximated in **Step 5**?

   ____

7. Turn the frequency control fully counterclockwise (2 kHz). Connect the AC voltmeter across **L_1**. Turn the frequency control clockwise until the voltage across **L_1** is maximum. Is the frequency control now set to the same point that was marked in **Step 5**? ___________________.

   The voltage across **L_1** at this point is: (E_L =_______________ VAC)

   Is this voltage higher than the generator input voltage (E_{IN}) that you measured in **Step 5**? ____________________________________ .

8. Turn the frequency control fully counter clockwise (2 kHz). Connect the AC voltmeter across **C_I**. Turn the frequency control clockwise until the voltage across **C1** is maximum. Is the frequency control now set to the same point that was marked in step 5? __________________ .

   The voltage across **C1** at this point is: (E_C = _______________ VAC).

   Is E_C approximately equal to E_L? ___________________________.

9. Turn the frequency control fully counter clockwise (2 kHz). Connect the voltmeter across both the coil and the capacitor. Turn the frequency control clockwise until the voltmeter reading is minimum. Is the frequency control now set at the same point that was marked in **Step 5**?

   The voltage across $C_1$and L_1 is: (_____________VAC).

   Does the voltage across L_1 completely cancel the voltage across C_1? _________

10. Using the equation for **$Q=E_L/ E_{IN}$**, compute the Q of the circuit. Use the value of **E_{IN}** measured in **Step 5**. Q = __________________

11. Using the equation for **E_L**, compute inductive reactance of the circuit. Use 107 mH as the value of L and the frequency computed in **Step 6**. X_L= _____ Ohms

12. Use the equation for X_C and compute the capacitive reactance of the circuit. Use 0.001 µF as the value of C and the frequency computed in **Step 6**.

   (X_C= _____________Ohms).

   Are X_L and X_C approximately equal? ___________________

13. Compute the bandwidth of the circuit. (**BW** =________ Hz). What are the frequencies at the half-power points? (_______ Hz and ______ Hz).

14. Place the voltmeter across the coil and carefully set the frequency control for maximum voltage across **L**. ($E_{L\ (max)}$ = _______________ VAC).

15. Multiply this voltage by **0.707** to find the voltage at the half-power points. Record the answer. (_____________ VAC).

16. Slowly turn the frequency control counter clockwise until the voltage across **L** is the value computed in **Step 15**.

   What is the frequency at this point? ___________ Hz.

   Mark this point on the frequency dial as **f_l.**

17. Slowly turn the frequency control clockwise, through the resonant point and beyond until the voltage across L is the value computed in **Step 15**.

    What is the frequency at this point? ___________ Hz.

    Mark this point on the frequency dial as $\mathbf{f_2}$.

18. Replace the 1000 Ω resistor ($\mathbf{R_1}$) with a jumper wire. Try to predict the effect this will have on:

    $\mathbf{f_0}$ = ________________________. **Q** = ________________________.

    $\mathbf{E_C}$ = ________________________. $\mathbf{E_L}$ = ________________________.

    $\mathbf{E_{IN}}$ = ________________________. **BW** = ________________________.

19. Set the frequency control fully counter clockwise (2 kHz). Connect the voltmeter across **L**. Carefully adjust the frequency control until E_L is maximum. Note the frequency at which this occurs.

    Has the resonant frequency changed? _____________________

20. Measure the voltage across the coil and record. (E_L =__________VAC.)

    How has E_L changed from the value measured in **Step 14**? (______________)

21. Set the frequency control fully counter clockwise (2 kHz). Connect the voltmeter across C. Adjust the frequency control until E_C is maximum. Note the frequency at which resonance occurs.

    f_0 = __________________________.

    E_C = __________________________.

22. With the frequency control set to the resonant frequency, measure the generator output voltage. (E_{IN} = _______________VAC).

23. Using the value of $\mathbf{E_L}$ measured in **Step 20** and the value of $\mathbf{E_{IN}}$ measured in **Step 22**. Compute the new value of **Q**. (**Q** =___________________)

    Has the circuit **Q** increased or decreased? (______________________)

24. Compute the new bandwidth. (**BW** =_______________Hz.)

    Has the bandwidth increased or decreased? (______________________)

25. Multiply the value of $\mathbf{E_L}$ found in **Step 20** by **0.707** and record the answer.

    ____________________ VAC

26. Slowly turn the frequency control counter clockwise until the voltage across **L** is the value computed in **Step 25**. At this point is the frequency dial above or below the lower half-power point marked earlier? (___________)

27. Slowly turn the frequency control clockwise through the resonant point to the upper half-power point. Is this point above or below the upper half-power point marked earlier? (______________)

28. Replace the 0.001 μF capacitor with 0.01 μF capacitor. Compute the new resonant frequency. (**f_0** = _________________-Hz.)

    Has the bandwidth increased or decreased? (_____________________)

    Set the generator to the new resonant frequency by adjusting the frequency control until the voltage measured across either the coil or the capacitor is maximum. Does the dial reading agree with the computed frequency? (_____)

29. Reconstruct the circuit shown in Fig. 1-1. Set the generator range switch to maximum and connect the AC voltmeter across C_1..

30. Turn the frequency control fully counter clockwise. The voltage across the capacitor at this frequency is: (**E_C** =______________ VAC.)

31. Using a pencil, mark this voltage on the far left vertical line of the graph shown in Fig. 1-2.

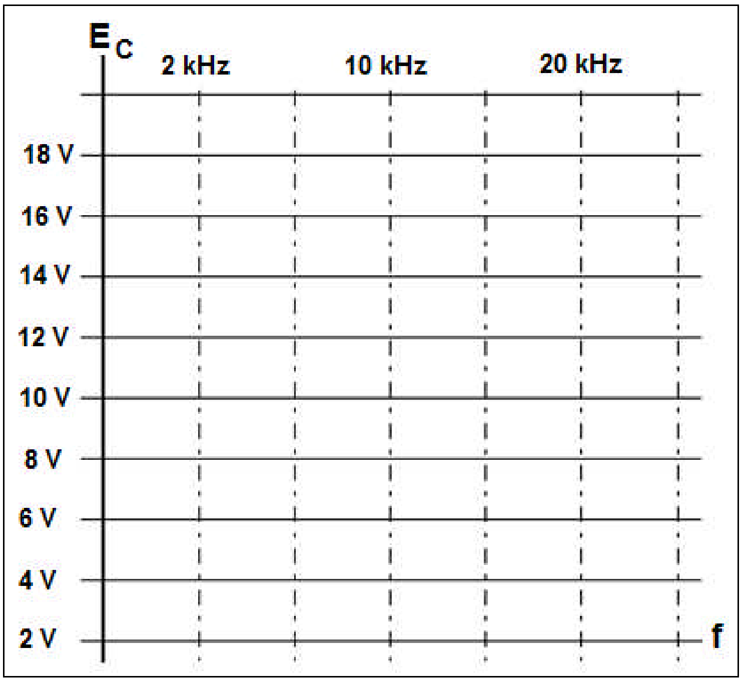


Fig. 1-2 Resonant Curve Plot

32. Rotate the frequency control clockwise to halfway between the leftmost mark on the dial and the point labeled 2 kHz. The voltage across the capacitor at this point is: (**f_C** = ___________________VAC.)

    Mark this voltage on the graph halfway between the left vertical line and the vertical line labeled 2 kHz.

33. Rotate the frequency control clockwise to the point marked 2 kHz.

    (E_C = _________________ VAC.)

    Mark this volt-age on the graph at the vertical line labeled 2 kHz.

34. Continue to turn the frequency control clockwise. Measure and plot E_C at each of the marked points on the frequency dial and at several points in between. Try to plot at least 20 different points across the frequency range.

35. Connect the plotted points with a continuous line so that a response curve is formed. At what frequency is **E_C** maximum? (____________ Hz)

    What is the value of **E_C** at this frequency? (E_C = ________VAC)

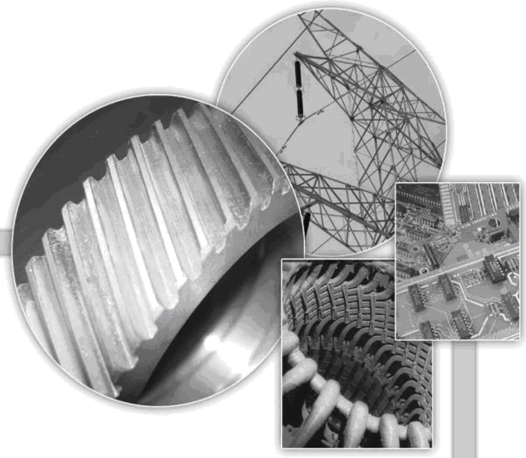
36. Multiply the value of **E_C** by 0.707 and record the answer below. (________VAC)

    Mark this voltage on the curve at the points above and below resonance.

    (________VAC)

37. Place a second 1 kΩ resistor in series with R_1 so that the total resistance in series with **L** and **C** is 2 kΩ.

38. Repeat **Steps 30** through **36** for this new circuit. Plot the new response curve in Fig. 1-2.



LESSON 2.4

SINGLEAND THREE PHASEPOWER

LESSON 2.4

SINGLE AND THREE PHASE POWER

OVERVIEW

This lesson deals with single and three phase power and its application concepts in Generation, Transmission and Distribution.

OBJECTIVES

Upon completion of this lesson, the trainees should be able to:

- Analyze the single and three phase power circuits.
- Convert WYE-Δ configuration and vice versa.
- Apply 3-ϕ conversion rules to power components to calculate Apparent and Real power.

Task 2.4-1: Single and Three Phase Power Measurement

INTRODUCTION

Alternating current is divided into **single-phase** and **three-phase** types. Single-phase power is used for small electrical demands such as found in the home. Three-phase power is used where large blocks of power are required, such as found in commercial applications and industrial plants.

Fig. 2.4-1(a, b) shows single phase alternator and the waveform from the output of an alternator respectively.

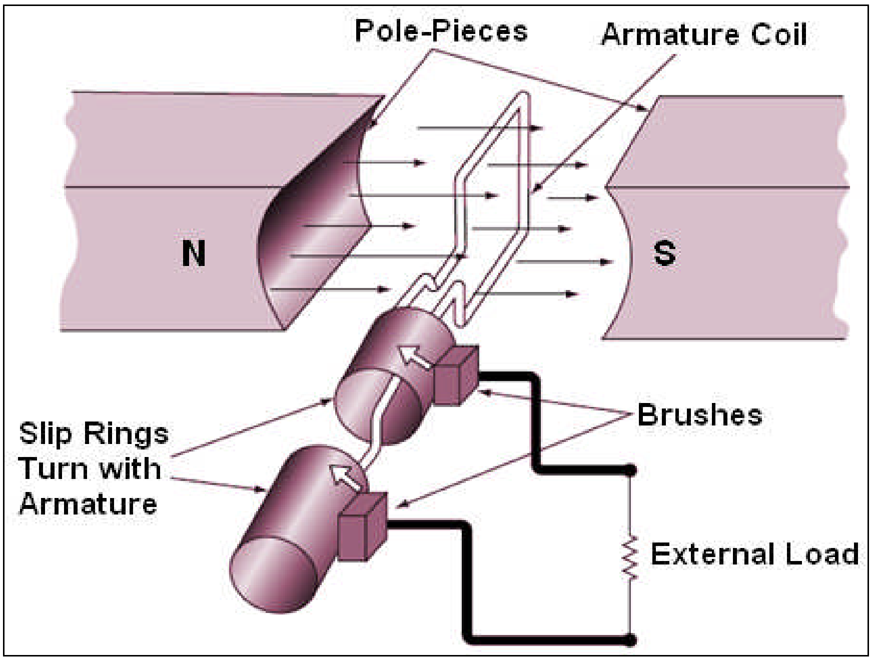


Fig. 2.4-1(a) Single Phase Alternator

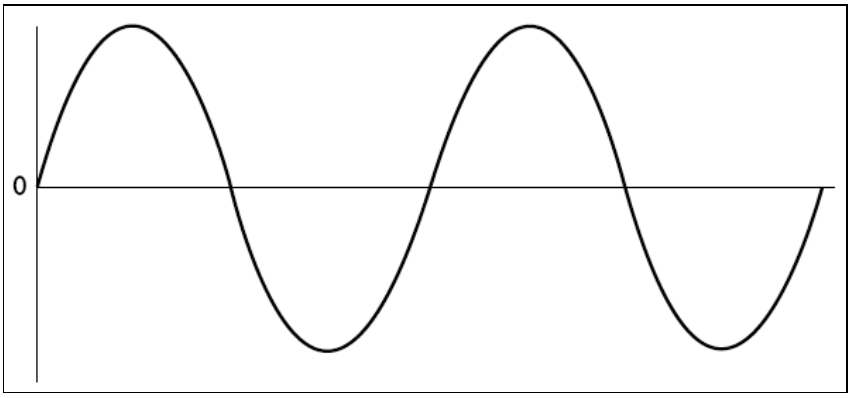


Fig. 2.4-1(b) A.C. Waveform

PROPERTIES OF AC SIGNALS

An electrical signal is a voltage or current, which conveys information, usually it means a voltage. The term can be used for any voltage or current in a circuit.

The voltage-time graph (Fig. 2.4-2) shows various properties of an electrical signal. In addition to the properties labeled on the graph, there is frequency which is the number of cycles per second.

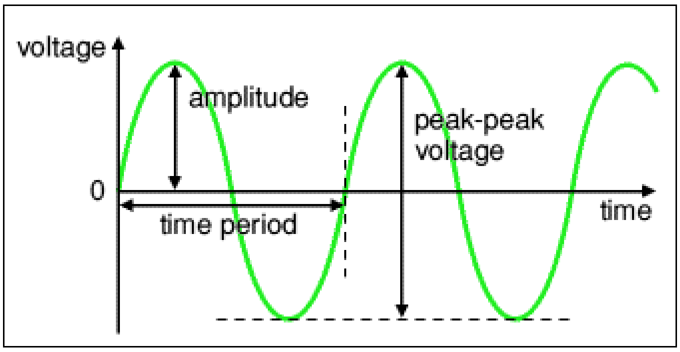


Fig. 2.4-2 Voltage-Time Graph

- **Amplitude** is the maximum voltage reached by the signal. It is measured in **volts, V.**
- **Peak voltage** is another name for amplitude.
- **Peak-peak voltage** is twice the peak voltage (amplitude). When reading an oscilloscope trace it is usual to measure peak-peak voltage.
- **Time period** is the time taken for the signal to complete one cycle.

  It is measured in **seconds (s).** but time periods tend to be short so **milliseconds (ms)** and microseconds (**µs)** are often used. 1ms = 0.001s and 1µs = 0.000001s.
- **Frequency** is the number of cycles per second-It is measured in **hertz (Hz),** but frequencies tend to be high so **kilohertz (kHz)** and **megahertz (MHz)** are often used. 1 kHz = 1000Hz and 1 MHz = 1000000Hz.

  Mains electricity in the Saudi Arabian kingdom has a frequency of **60Hz.**

ROOT-MEAN-SQUARE (RMS) VALUES

The value of an AC voltage is continually changing from zero up to the positive peak, through zero to the negative peak and back to zero again. Clearly for most of the time it is less than the peak voltage, so this is not a good measure of its real effect.

Instead we use the **root-mean-square-voltage** (V_{rms}), as shown in Fig. 2.4-3, which is 0.7 of the peak voltage (V_{peak}):

$\mathbf{V_{rms} = 0.7\ V_{peak}}$ **and** $\mathbf{V_{peak} = 1.4\ V_{rms}}$

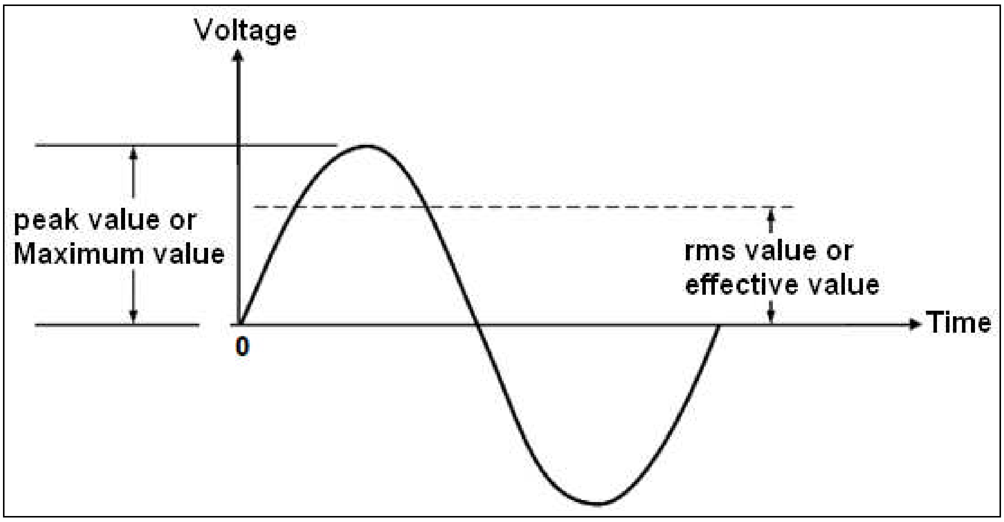


Fig. 2.4-3 Root-Mean-Square Voltage

NOTE

AC voltmeters and ammeters show the rms value of the voltage or current.

SINGLE-PHASE AC POWER

For the DC circuits, power in watts is equal to the product of voltage and current, it gives the true power of a DC circuit and is the amount of power actually consumed by the circuit.

In an AC circuit the product of voltage and current is the **apparent power** and is only equal to true power if the voltage and current are in phase.

If the voltage and current are out of phase apparent power is composed of both **true power** and **reactive power**

The majority of AC circuits contain a combination of inductance and resistance, so that the voltage and current are out of phase. The presence of impedance (resistance and reactance) in AC circuits causes the current to lag the voltage by a number of degrees which depends on the amount of reactance in the circuit.

THE POWER TRIANGLE

These three types of power: true, reactive, and apparent relate to one another in trigonometric form. We call this the **power triangle** (Fig. 2.4-4).

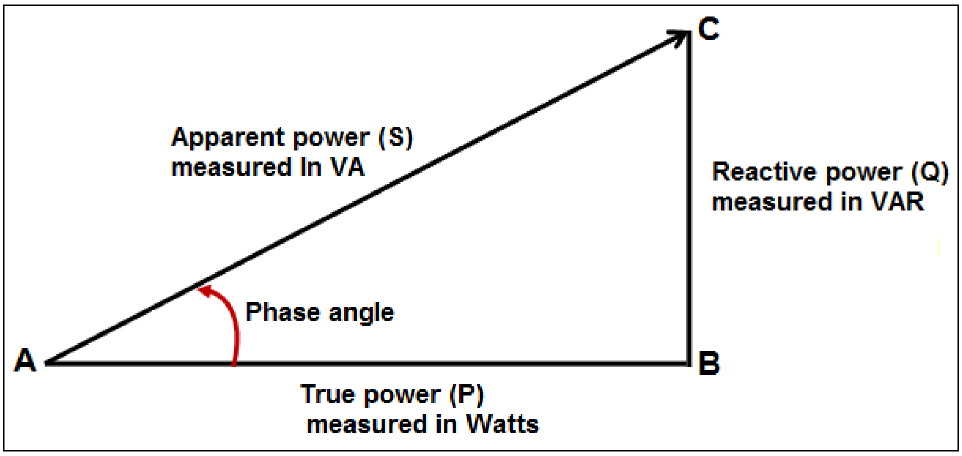


Fig. 2.4-4 the Power Triangle

APPARENT POWER

Power in an AC circuit is the vector sum of true power and reactive power. This is called **apparent power** True power is equal to apparent power in a purely resistive

circuit because voltage and current are in phase. Voltage and current are also in phase in a circuit containing equal values of inductive reactance and capacitive reactance

The apparent power relationships for inductive and capacitive circuits are

$$\mathbf{S = I^2Z = \frac{V^2}{Z} \quad (VA)}$$

$$\mathbf{S = \sqrt{P^2 + Q^2} \quad (VA)}$$

Where:

S = Apparent power (VA)

P = True power (Watt)

Q = Reactive power (VAR)

Z= Impedance (Ω)

TRUE POWER (ACTIVE POWER)

Power consumed by a resistor is dissipated in heat and not returned to the source. This is called **true power** because it is the rate at which energy is used and is measured in watts.

The active power relationships for resistive circuits are the same for A.C. as for D.C.

$$\mathbf{P = I^2\, R = \frac{V^2}{R} \quad (Watt)}$$

REACTIVE POWER

Current in an AC circuit rises to peak values and diminishes to zero many times a second. The energy stored in the magnetic field of an inductor, or plates of a capacitor, is returned to the source when current changes direction.

Although reactive components do not consume energy, they do increase the amount of energy that must be generated to do the same amount of work. The rate at which this non-working energy must be generated is called **reactive power**

The reactive power relationships for inductive and capacitive circuits are:

$$\mathbf{Q = I^2X = \frac{V^2}{X} \quad (VAR)}$$

EXAMPLE 2.4-1

For the RL circuit of Fig. 2.4-5, I = 5 A. Determine active and reactive power?

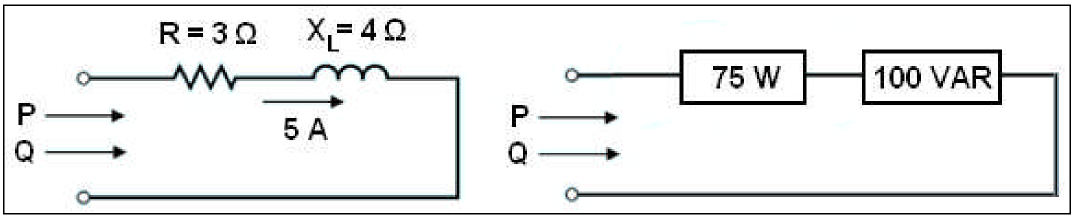


Fig. 2.4-5 Example 2.4-1

SOLUTION

Active Power P = $5^2 \times 3 = 75$ W

Reactive Power = $5^2 \times 4 = 100$ VAR

VOLTAGES IN THREE-PHASE SYSTEM

Three-phase voltages are often produced with a three-phase A.C. generator (or alternator) whose cross-sectional view is shown in Fig. 2.4-6(a). The generator basically consists of a rotating magnet (called the **rotor**) surrounded by a stationary winding (called the **stator**). Three separate windings or coils **A**, **B**, and **C** are physically placed **120°** apart around the stator.

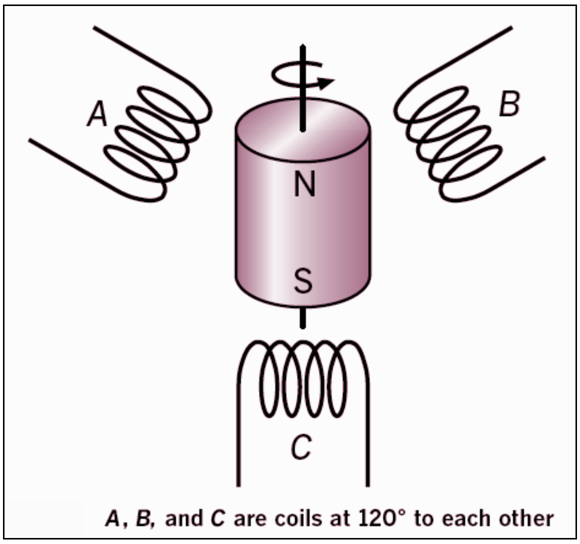


Fig. 2.4-6(a) Simple Three-Phase Alternator

As the rotor rotates, its magnetic field induces voltages in the stator coils. Because the coils are placed 120° apart, the induced voltages in the coils are equal in magnitude but out of phase by 120°, as shown in Fig. 2.4-6(b).

Since each coil can be regarded as a single-phase generator by itself, the three-phase generator can supply power to both single-phase and three-phase loads.

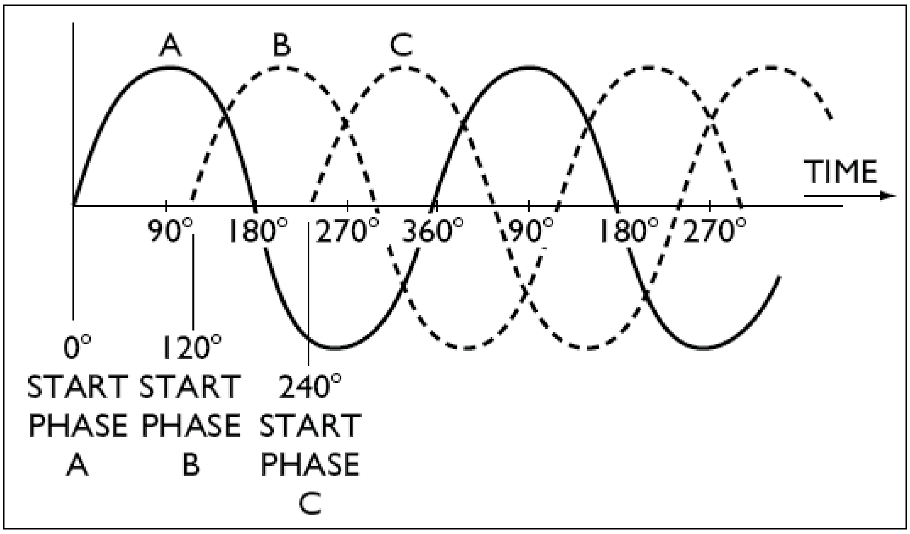


Fig. 2.4-6(b) Three-Phase Voltage Sine Waves

The windings shown in Fig. 2.4-6(a) can be connected in two ways:

- Wye connection **Y** (Fig. 2.4-7)
- Delta connection Δ (Fig. 2.4-9)

WYE CONNECTION

In wye connection:

- Line voltage $V_L = \sqrt{3}$ Phase voltage V_{PH}
- Line current I_L = Phase current I_{PH}

Where: $\sqrt{3} = 1.732$

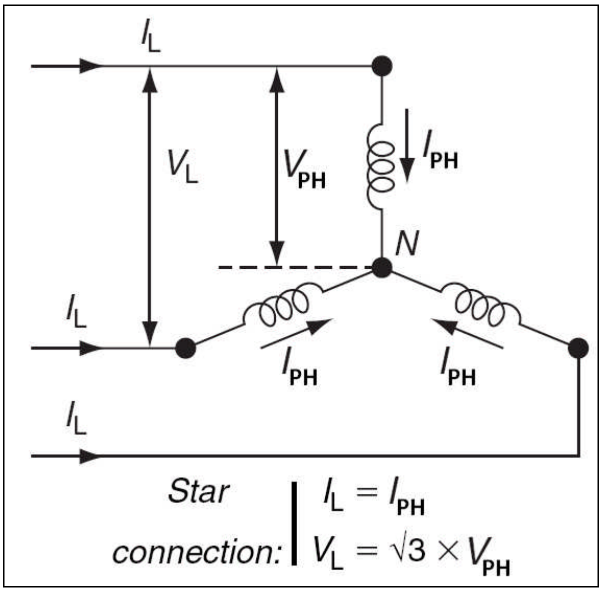


Fig. 2.4-7.Wye Connection

In a **Three-Phase Power Distribution System** (Fig. 2.4-8), the power consumed by the loads connected across the phases should be equal. The three-phase, 4-wire circuit is used to supply lighting loads.

This circuit has a **Neutral Line**, which is usually connected, to ground at the service transformer. The **Neutral Line:**

- Carries no current when the loads are balanced.
- Carries the unbalanced portion of the current when loads are unbalanced.

The wye connected three-phase; 4-wire system is used to supply power to different types of loads.

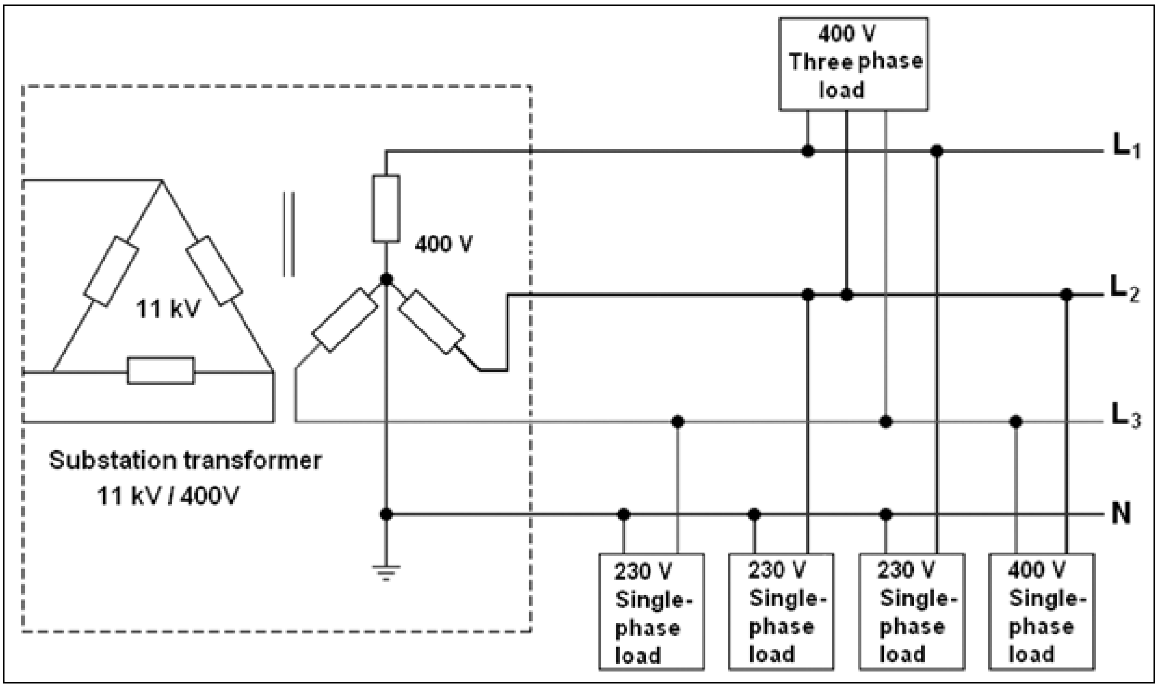


Fig. 2.4-8 Three-phase Four-Wire Distribution

THREE PHASE POWER IN STAR CONNECTION

In the three phase system, the power in each phase is product of the phase voltage, phase current and power factor. The total power is three times the single-phase power, so that:

Total Power = 3 V_{PH} I_{PH} Cos ϕ

Where:

Cos ϕ = power factor (P.F) ϕ = Phase angle between voltage and current

In star connection:

$V_L = \sqrt{3} V_{PH}$ $V_P = V_L / \sqrt{3}$

Total 3-ϕ Power = 3 V_{PH} I_{PH} Cos ϕ = 3 ($V_L / \sqrt{3}$) I_L Cos ϕ = $\sqrt{3}$ V_L I_L Cos ϕ

Total Power = $\sqrt{3}$ V_L I_L Cos ϕ

DELTA CONNECTION

In delta connection:

- Line voltage $\mathbf{V_L}$=phase voltage $\mathbf{V_{PH}}$
- Line voltage $\mathbf{I_L}$=1.732 phase voltage $\mathbf{I_{PH}}$

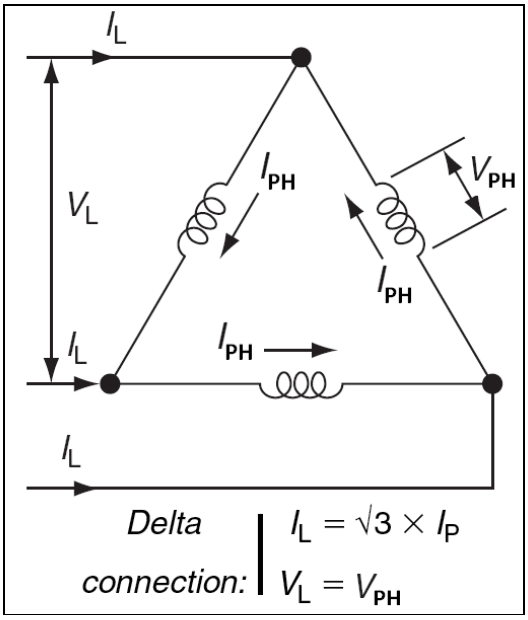


Fig. 2.4-9.Delta Connection

THREE-PHASE POWER IN DELTA CONNECTION

In Star Connection

$V_L = \sqrt{3} V_{PH}$ $\qquad V_P = V_L / \sqrt{3}$

$$\textbf{Total Power} = 3\,V_{PH}\,I_{PH}\,\cos\phi = \frac{3\,V_L\,I_L}{\sqrt{3}}\cos\phi = \sqrt{3}\,V_L\,I_L\cos\phi \;\;(\textbf{Watt})$$

The **advantages** of three-phase power over single-phase power are that a three-phase system has:

- A more constant level of power.
- Smaller operating machines with better operating characteristics.
- Lower cost.

- Both high and low single-phase voltages.
- Service for both single and three-phase loads.

MEASURING THREE-PHASE POWER

THREE-WATTMETER METHOD

The three-phase power can be measured by three single-phase wattmeters having current coils in each line and potential coils connected across the given line and any common junction

Fig. 2.4-10 shows the connection diagram for Three-wattmeter connection method of measuring three-phase power. The total real power delivered to the load is given by **the algebraic sum** of the three wattmeter readings.

$\mathbf{P = W_A + W_B + W_C}$

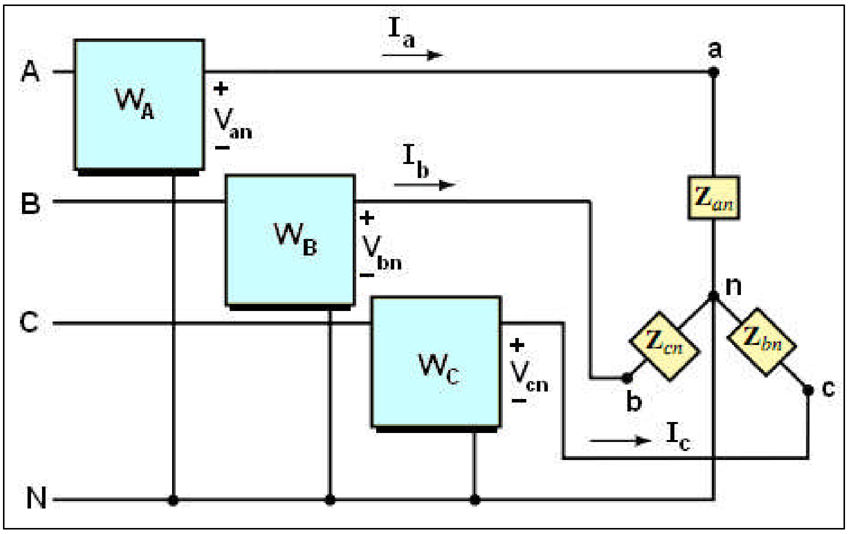


Fig. 2.4-10 Three-Wattmeter Method

TWO-WATTMETER METHOD

Three-phase power can be measured by means of only two single-phase wattmeters having a common potential junction on any of the three lines in which there is no current coil. This is known as the **two-wattmeter method of measuring three-phase power.**

Fig. 2.4-11 shows the connection diagram for the two-wattmeter method of measuring three-phase power. The total real power delivered to the load is given by **the algebraic sum** of the two wattmeter readings.

$\mathbf{P = W_A + W_C}$

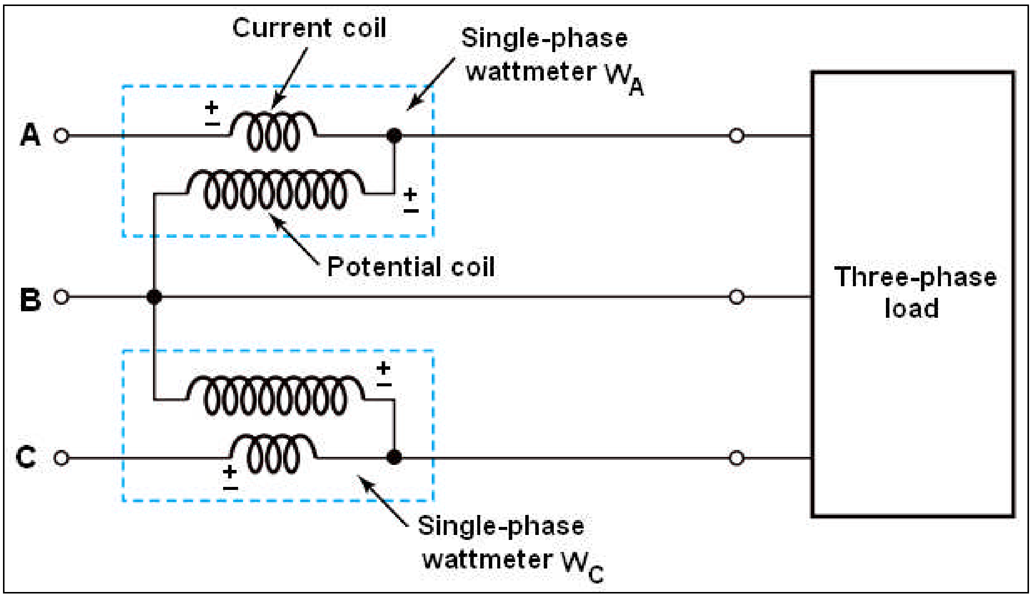


Fig. 2.4-11 Two-Wattmeter Method

EXAMPLE 2.4-2

Calculate the three-phase power for a circuit with a Power Factor of 0.75, line voltage and line current as follows:

V_L = 240 volts

I_L = 10.5 Amperes

SOLUTION

To find power, calculate as follows:

$$P = \sqrt{3}\, V_L\ I_L \times PF$$
$$= \sqrt{3} \times 240\ V \times 10.5\, A \times 0.75 = 3274\ Watts = 3.27\ kW$$

EXAMPLE 2.4-3

Calculate the three-phase power for a circuit with a Power Factor of 0.85, line voltage V_L = 480 volts and line current I_L = 5.5 amperes:

SOLUTION

To find power, calculate as follows:

$$P = \sqrt{3}\, V_L\ I_L \times PF$$
$$= \sqrt{3} \times 480\ V \times 5.5\ A \times 0.85 = 3887\ Watts = 3.89\ kW$$

EXAMPLE 2.4-4

For Fig. 2.4-12, determine the wattmeter reading.

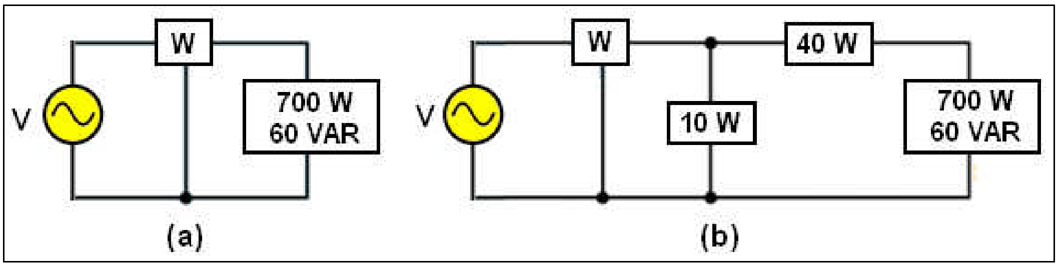


Fig. 2.4-12 Example 2.4-4

SOLUTION

(a) A wattmeter reads only active power. Thus, it indicates 700 W.

(b) A wattmeter reads only active power. Thus, it indicates:

10 + 40 + 700 = 750 W

Y TO Δ CONVERSION

Impedances connected in a Δ configuration are equivalent to a unique **Y** configuration. Fig. 2.4-13 shows the equivalent circuits.

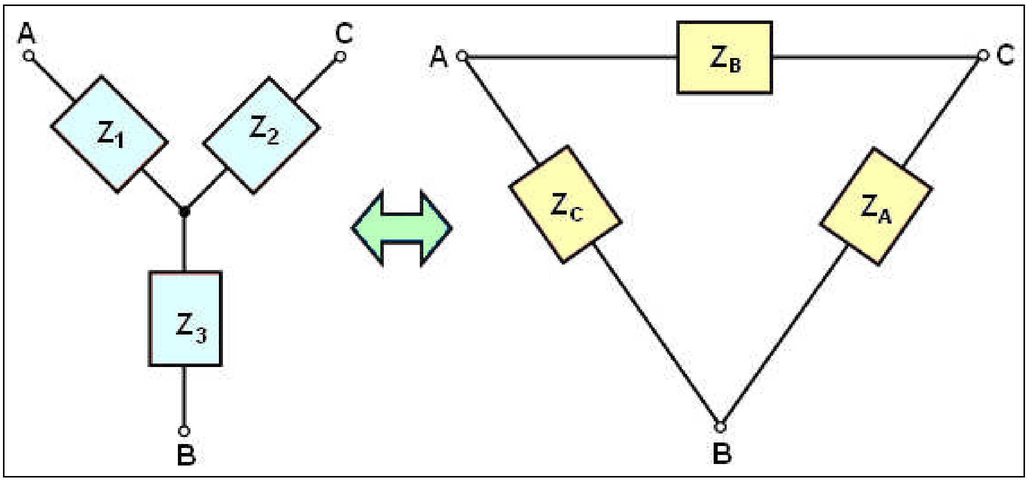


Fig. 2.4-13 Delta-Wye Equivalence

Y TO Δ CONVERSION

$$Z_1 = \frac{Z_B Z_C}{Z_A + Z_B + Z_C}$$

$$Z_2 = \frac{Z_A Z_C}{Z_A + Z_B + Z_C} \qquad \text{or} \qquad Z_Y = \frac{\text{Product of two adjacent Z's in } (\Delta)}{\text{Sum of all Z's in } (\Delta)}$$

$$Z_3 = \frac{Z_A Z_B}{Z_A + Z_B + Z_C}$$

Δ TO Y CONVERSION

$$Z_a = \frac{Z_1Z_2 + Z_1Z_3 + Z_2Z_3}{Z_1}$$

$$Z_b = \frac{Z_1Z_2 + Z_1Z_3 + Z_2Z_3}{Z_2} \qquad \text{OR} \qquad Z_\Delta = \frac{\text{Sum of all cross products in (Y)}}{\text{Opposite (Z) in (Y)}}$$

$$Z_c = \frac{Z_1Z_2 + Z_1Z_3 + Z_2Z_3}{Z_2}$$

SUMMARY

- Alternating current is divided into single-phase and three-phase types.
- Single-phase power is used for small electrical demands such as found in the home.
- Three-phase power is used where large blocks of power are required, such as found in commercial applications and industrial plants.
- For the DC circuits, power in watts is equal to the product of voltage and current
- In an AC circuit the product of voltage and current is the apparent power.
- If the voltage and current are out phase apparent power is composed of both true power and reactive power.
- Three-phase voltages are often produced with a three-phase A.C. generator.
- Three phase windings can be connected in two ways:
  - Wye connection.
  - Delta connection.
- In the three phase system, the power in each phase is product of the phase voltage, phase current and power factor.
- The total power in a 3-phase Delta system is the same as for a wye connected system.

FORMULAS

$$P = I^2R = \frac{E^2}{R} \text{ Watt}$$

$$Q = I^2X = \frac{E^2}{X} \text{ VAR}$$

$$S = I^2Z = \frac{E^2}{Z} \text{ VA}$$

$$S = \sqrt{P^2 + Q^2} \text{ VA}$$

$$\text{Total power} = 3\, V_{PH}\, I_{PH} \text{ Cos } \phi = \frac{3\, V_L I_L}{\sqrt{3}} \text{ Cos } \phi = \sqrt{3}\, V_L\, I_L \text{ Cos } \phi \text{ (Watt)}$$

GLOSSARY

Alternating current (AC)	Current that periodically reverses direction
Frequency	The rate of variation of a periodic waveform
Effective value	A measure of the amplitude of alternating current or voltage. Also called the root-mean-square or RMS value. Test meters used to measure alternating current or voltage usually display effective values
Apparent power	The vector sum of true power and reactive power
True power	Also called real power, true power is the power dissipated by circuit resistance
Reactive power	Power associated with inductance or capacitance. the unit for reactive power is the VAR
Wye	A connection arrangement used for the primary and/or secondary of a three-phase transformer
Delta	A connection arrangement used for the primary and/or secondary of a three-phase transformer.
Neutral	A reference connection in a power distribution system

REVIEW EXERCISE

1. Calculate line voltage for the **Wye** connection in Fig. 2.4-14

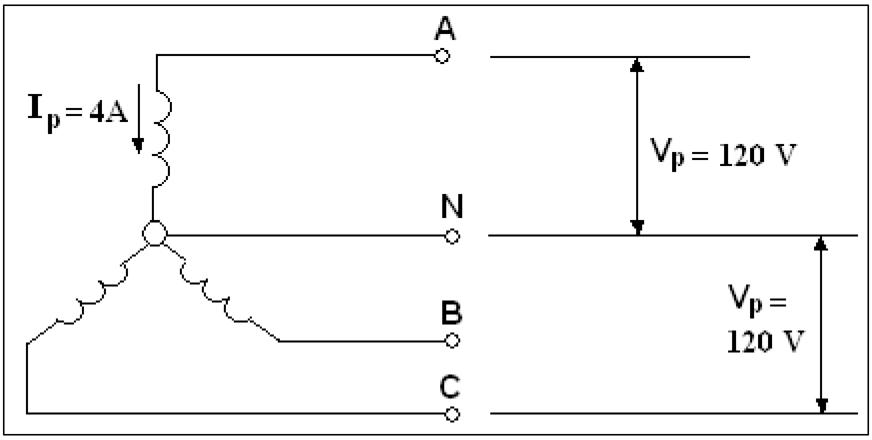


Fig. 2.4-14

2. Determine the line current for the connection in Fig. 2.4-14.
3. Calculate the phase voltage for the connection in Fig. 2.4-14, if the line voltage is 277 volts.
4. Calculate the line voltage for the connection in Fig. 2.4-14, if the phase voltage is 360 V.
5. Calculate the line current for the delta connection shown in Fig. 2.4-15.

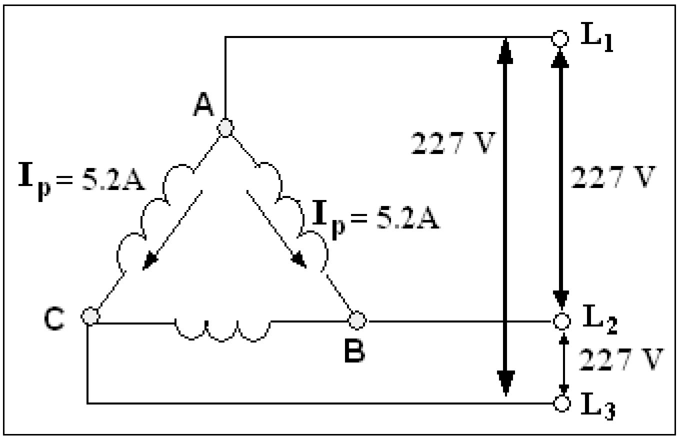


Fig. 2.4-15

6. Determine the phase voltage (V_P) for the delta connection in Fig. 2.4-15.

7. Calculate the line current for the connection in Fig. 2.4-15 when the phase current (I_P) is 20.5 Amps.
8. Calculate the phase current for the connection in Fig. 2.4-15 when the line current is 0.63 Amps.
9. Calculate the line voltage for the **Wye** connection shown in Fig. 2.4-16.

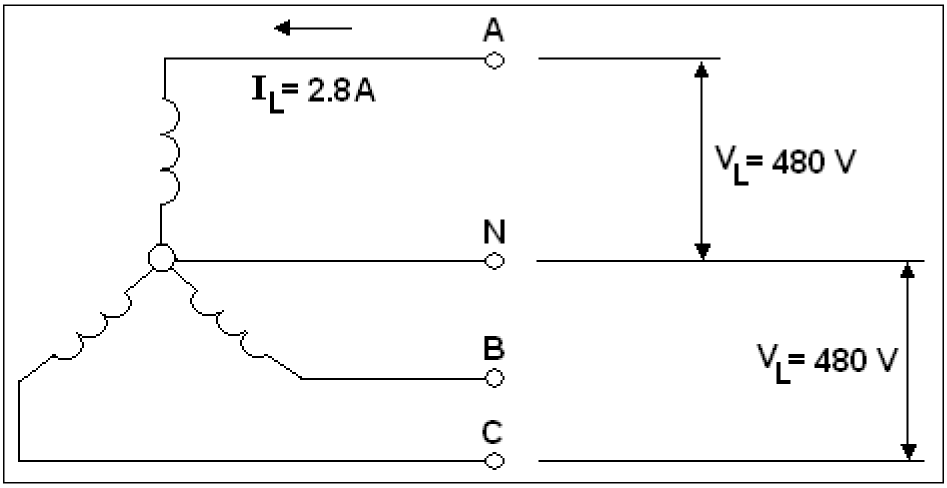


Fig. 2.4-16

10. Determine the phase current for the connection in Fig. 2.4-16.

TASK 2.4-1

SINGLE AND THREE PHASE POWER MEASUREMENT

OBJECTIVES

Upon completion of this task, the trainees should be able to:

- Familiarize with 3-ϕ Δ-Y/Y-Δ connections.
- Measure 1-ϕ and 3-ϕ power in Watts.

EQUIPMENT AND MATERIALS REQUIRED

- 3 - 1-ϕ Transformers
- 1 - 3-ϕ power Supply
- 1 – Wattmeter
- 1- AC Voltmeter
- 1- AC Ammeter
- 3 - 110VAC Lamps (L1)
- 3 - 220VAC Lamps (L2)

SAFETY PRECAUTIONS

- Trainees should adhere to personal and equipment safety as per safety procedures.
- Follow normal Lab Safety rules.
- Follow all instructions from Instructor.
- Don’t wear watches or jewelry while performing practical hands–on tasks.
- Use suitable insulated wire, tools, measuring instruments and power supplies.
- Don't short any voltage circuit.
- Keep all current circuits closed at all times.
- Select suitable instruments with appropriate ranges before use.

PROCEDURE

1. Ensuring the 3-ϕ, power is switched off, connect the 3-ϕ power circuit, as shown in Fig. 1-1(a) to 380VAC power supply.
2. Call the instructor to check the accuracy of the wiring.
3. Turn the power switch ON and measure phase voltage and current to the load lamps **(L1)** and power measured by the Wattmeter, as shown.

   V_P = ______ V I_P = ______A P_{meas} = ______ W

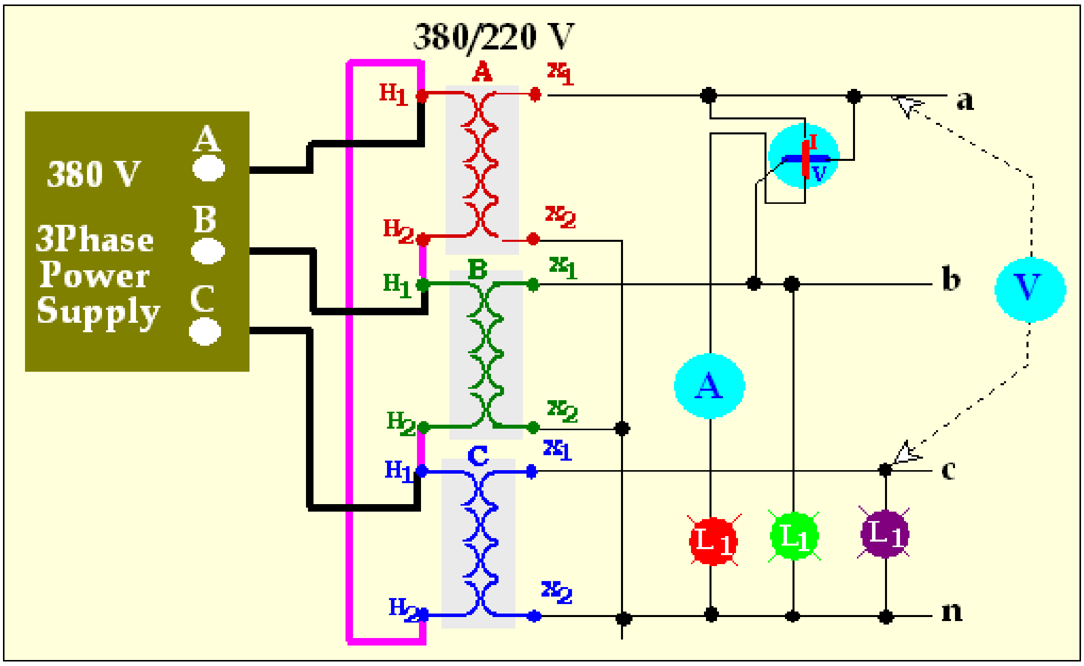


Fig. 1-1(a)

4. Using the appropriate formulas to calculate the 3-ϕ power delivered to the load.

   $\mathbf{V_L = \sqrt{3} \times V_P}$

   Total 3ϕ Power = $3\ V_P\ I_P = 3\ (V_L / \sqrt{3})\ I_L = \sqrt{3}\ V_L\ I_L$

   $P_T = 3\ P_{meas}$= ______ $3 \times V_P \times I_P$ = ______ W

   Is the total power measured same as calculated value?

   Yes: ______ No: ______

5. Turn the power switch OFF and connect load lamps between phase to phase.

6. Turn the power switch ON and measure phase voltage and current to the load lamps **(L2)**, as shown.

   $V_L = V_P =$ ______ V $\qquad I_L = \sqrt{3}$ Ip ______A $\qquad P_{meas} =$ ______ W

7. using the appropriate formulas, calculate the 3-ϕ power delivered to the load.

   $V_L = V_P$ and $\quad I_L = \sqrt{3}$ Ip $\quad I_P = I_L / \sqrt{3}$

   $$P_T = 3\,Vp\,Ip\,Cos\ \varphi = \frac{3\,V_L I_L}{\sqrt{3}} \cos\varphi = \sqrt{3}\,V_L I_L \cos\ \varphi$$

   $P_T = 3\ P_{meas} =$ ______ $= 3\ V_P \times Ip = \sqrt{3} \times V_L \times I_L =$ ______ W

   Is the total power measured same as calculated value?

   Yes: ______ No: ______

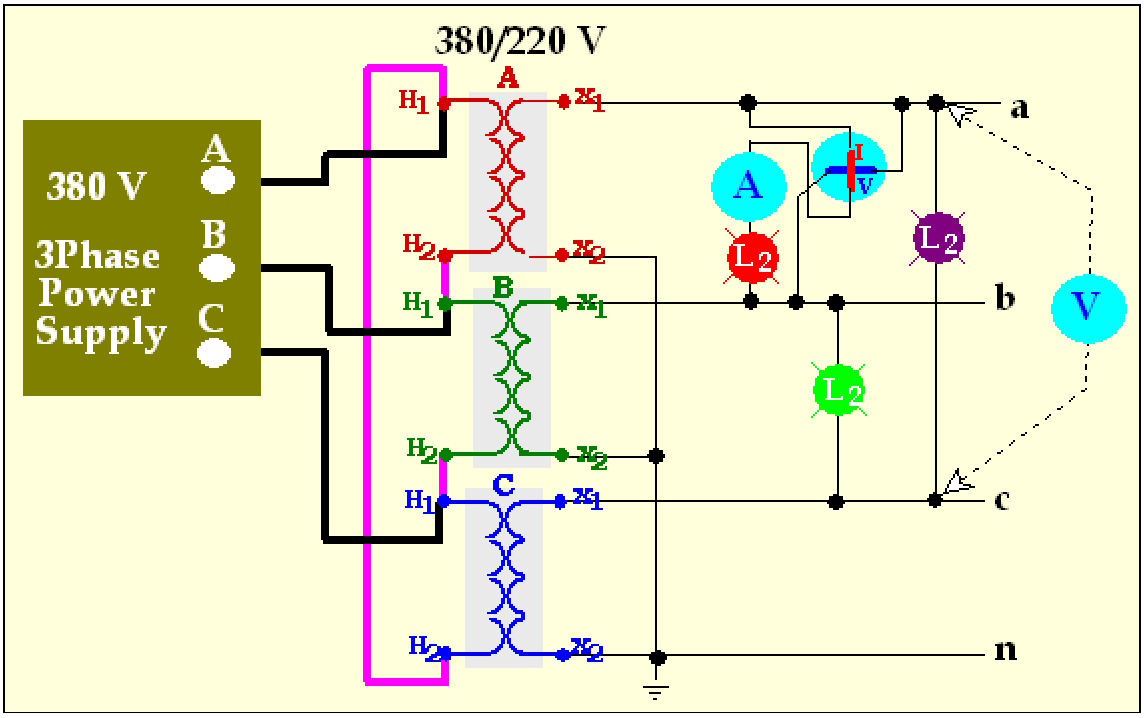
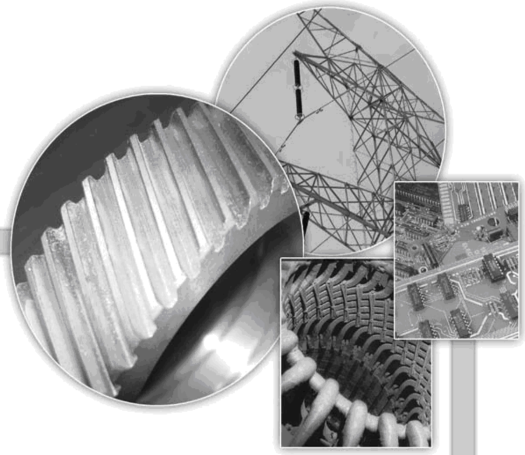


Fig. 1-1(b)



LESSON 2.5

POWERFACTOR

LESSON 2.5
POWER FACTOR

OVERVIEW

This lesson discusses the power factor, its effects and economics involved giving corrective methods to overcome lagging/leading Power Factor problems.

OBJECTIVES

Upon completion of this lesson, the trainees will be able to:

- Identify the components used to make the current to lead or lag.
- Describe the effect of low power factor.
- Discuss the procedures to correct power factors in a power system.

INTRODUCTION

Power factor is a very important concept in power distribution. If the power factor is a very small number, then little power is being consumed even though the current flowing through the system is very large. That's because the voltage and current are so far out of phase that little work is being done. Distributing power in this manner requires much more current-handling capability than is really necessary. Everything in the system has to be oversized to deliver the same amount of power.

The generator, power distribution cables, transmission towers, switches, transformers, breakers, and connectors all have to be oversized to handle the increase in current. In addition, the labor to install the larger system, including hundreds of miles of cables and distribution gear, adds to the inflated cost.

POWER FACTOR

These three types of power true:, reactive, and apparent- relate to one another in trigonometric form. We call this the **power triangle** (Fig. 2.5-1).

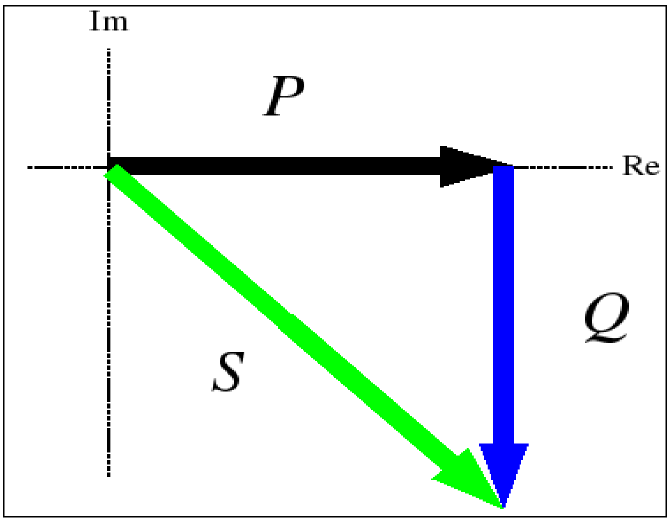


Fig. 2.5-1 Power Triangle

Power factor is the ratio of true power to apparent power in an AC circuit. Power factor is expressed in the following formula:

$$\textbf{Power Factor} = \frac{\textbf{True Power}}{\textbf{Apparent Power}}$$

$$\textbf{COS}\ \phi = \frac{\mathbf{P}}{\mathbf{S}}$$

NOTE

It should be noted that power factor, like all ratio measurements, is a unitless quantity.

PURE RESISTIVE CIRCUIT

In a purely resistive circuit (Fig. 2.5-2), where current and voltage are in phase, there is no angle of displacement between current and voltage. The cosine of a zero degree angle is one. The power factor is one. This means that all energy delivered by the source is consumed by the circuit and dissipated in the form of heat.

PURE INDUCTIVE CIRCUIT

In a purely inductive circuit (Fig. 2.5-2), current lags voltage by 90º. The cosine of a 90º angle is zero. The power factor is zero.

PURE CAPACTIVE CIRCUIT

In a purely capacitive circuit (Fig. 2.5-2), current leads voltage by 90º. The cosine of a 90º angle is zero. The power factor is zero.

NOTE

In a purely reactive circuit, the power factor is zero. This means the circuit returns all energy it receives from the source to the source.

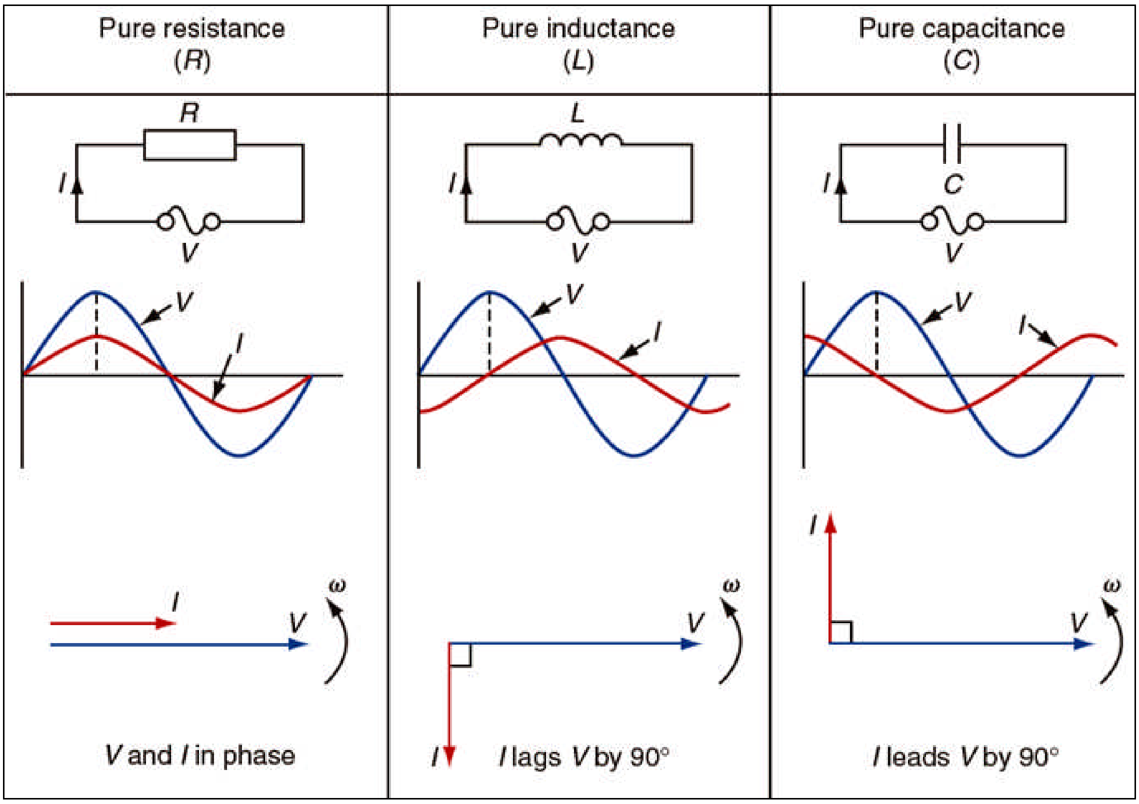


Fig. 2.5-2 Voltage and Current Relationships in Pure R, L, C Circuits

LAGGING POWER FACTOR

For a load containing only resistance and inductance (Fig. 2.5-3), the load current lags voltage by phase angle more than 0° and less than 90°. The power factor in this case is described as **lagging (**more than 0 and less than 1).

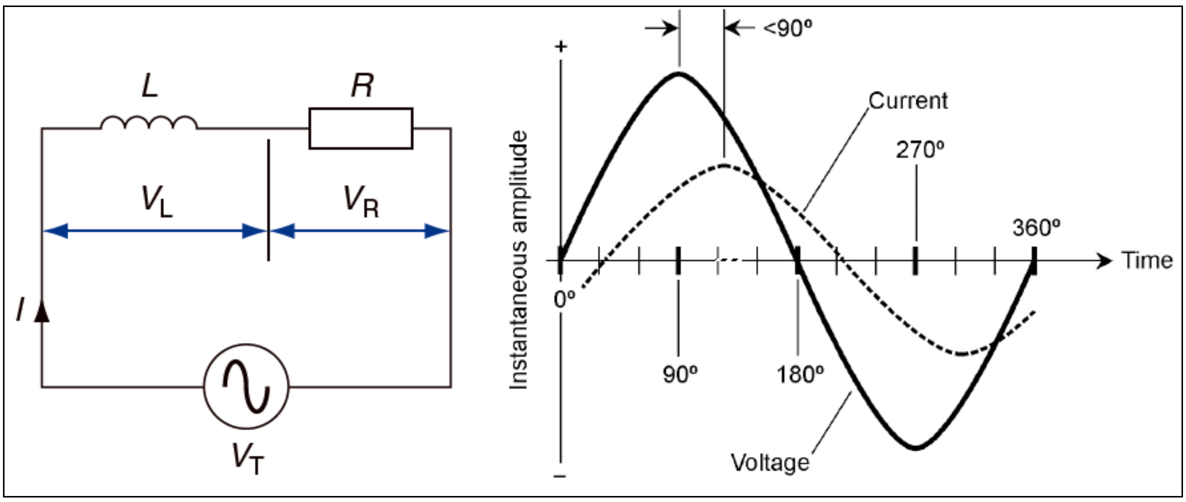


Fig. 2.5-3(a) Current Lags Voltage by Less Than 90°

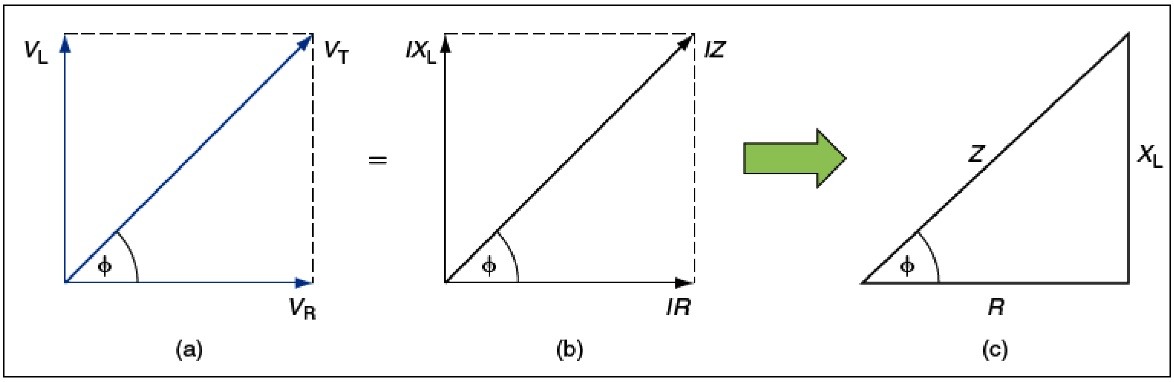


Fig. 2.5-3(b) Phasor Diagram and Impedance Triangle

LEADING POWER FACTOR

For a load containing only resistance and capacitive (Fig. 2.5-4), the load current leads voltage by phase angle more than 0° and less than 90°. The power factor in this case is described as **leading** (more than 0 and less than 1).

In a circuit where reactance and resistance are equal, voltage and current are displaced by 45°. The cosine of a 45° angle is .7071. The power factor is .7071

This means the circuit uses approximately 70% of the energy supplied by the source and returns approximately 30%

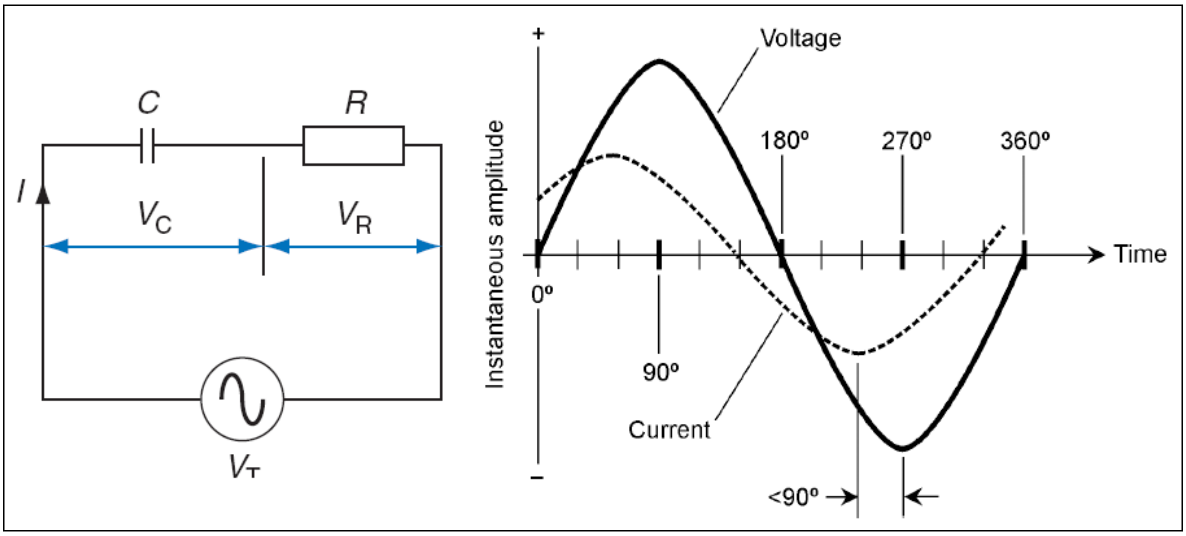


Fig. 2.5-4(a) Current Leads Voltage by Less Than 90°.

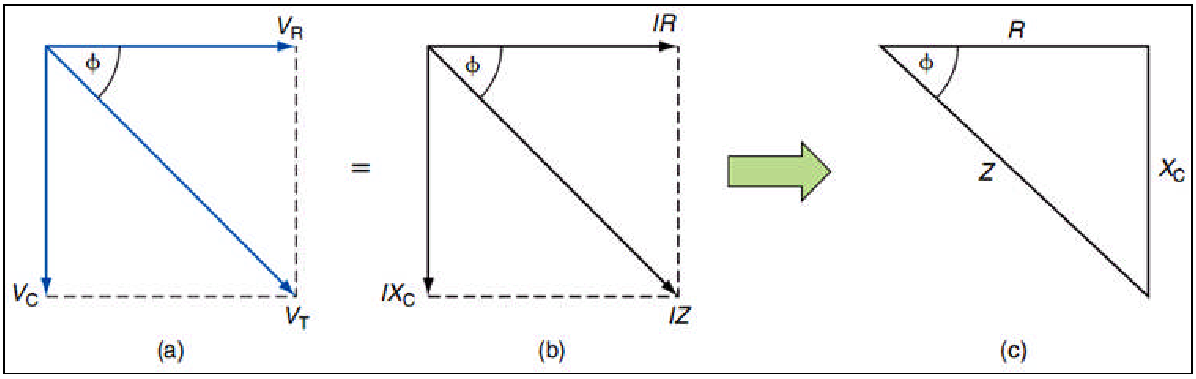


Fig. 2.5-4(b) Phasor Diagram and Impedance Triangle

EFFECT OF LOW POWER FACTOR

Inductors (transformers, chokes, coils, relays, and motors) used in an AC circuit will cause the current to lag on the voltage and producing a poor power factor.

Electrical energy supplied at low Power Factor is costly to the supplier as the larger currents require heavier cables and switchgear than that really necessary.

EXAMPLE 2.5-1

A 250-volt AC motor requiring 1000 watts is found to take 5 amperes. Calculate the power factor?

SOLUTION

$$\textbf{Power Factor (P.F)} = \frac{\textbf{True Power}}{\textbf{Apparent Power}} = \frac{\textbf{1000}}{\textbf{250} \times \textbf{5}} = \textbf{0.8 Lagging}$$

If the power factor had been 1 or unity, the true power would equal the apparent power and current of 4 amps would have been measured. The effect of having a power factor of 0.8 means that more current flows than is required to produce the power.

CORRECTING POWER FACTOR

The voltage on a circuit may fall below a specified level for some reasons, such as, connecting large motors to the system causes a momentarily drop in the system voltage. To maintain line voltage at constant value, capacitors are used

Capacitor (Fig. 2.5-5) improves the power factor for the system and allows more load to be connected to existing system.

Capacitor units (Fig. 2.5-6) are made of series and parallel combinations of capacitor packs or elements put together.

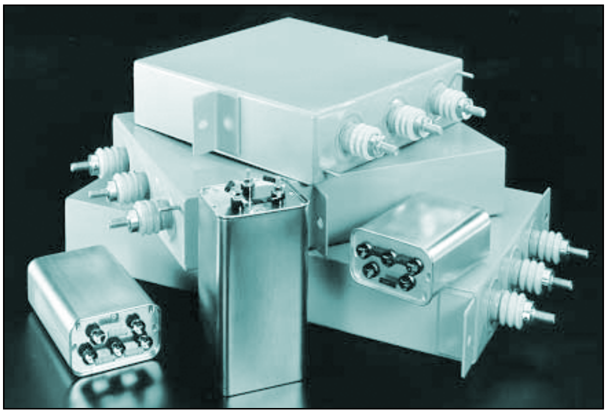


Fig. 2.5-5 Three-Phase Capacitor Unit

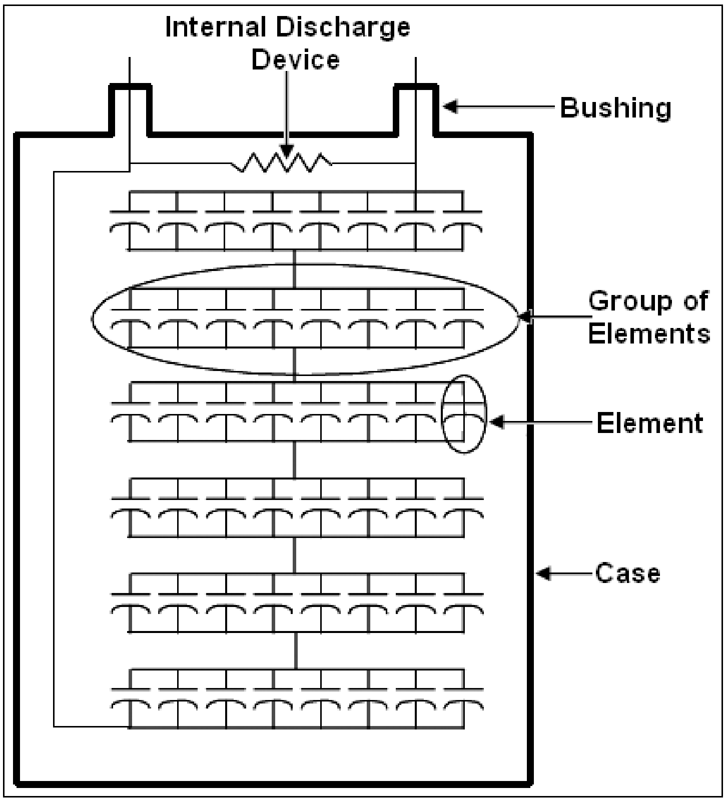


Fig. 2.5-6 Capacitor Unit Components

A capacitor, when connected to power system, is a static source of kilo-Vars. More of loads serviced by SEC are highly inductive in nature using induction motors. These inductive devices draw real power (kilo-Watts) and draw reactive power (kilo Vars).

In commercial use, the Power Factor should be close to unity for efficient distribution. However, the inductive load of motors will result in a Power Factor of 0.7, for the phase angle of 45°.

To correct for this lagging inductive component of the current in the main line, a capacitor can be connected across the line to draw leading current from the source. Since the capacitor has the effect of causing the current in an AC circuit to lead the voltage, the capacitor is installed in the line to introduce a corrective effect to the lagging current of an inductor by bringing it nearer into phase with the voltage. The value of capacitance is calculated to take the same amount of Volt-Amperes as the Vars of the load. In practice unity Power Factor is seldom achieved and a Power Factor of 0.9 is considered to be satisfactory.

An example of local capacitor bank application for the power factor correction is shown in Fig. 2.5-7. In this scheme, the individual loads are provided with separate capacitor banks. This type of reactive compensation is mainly suitable for industrial loads.

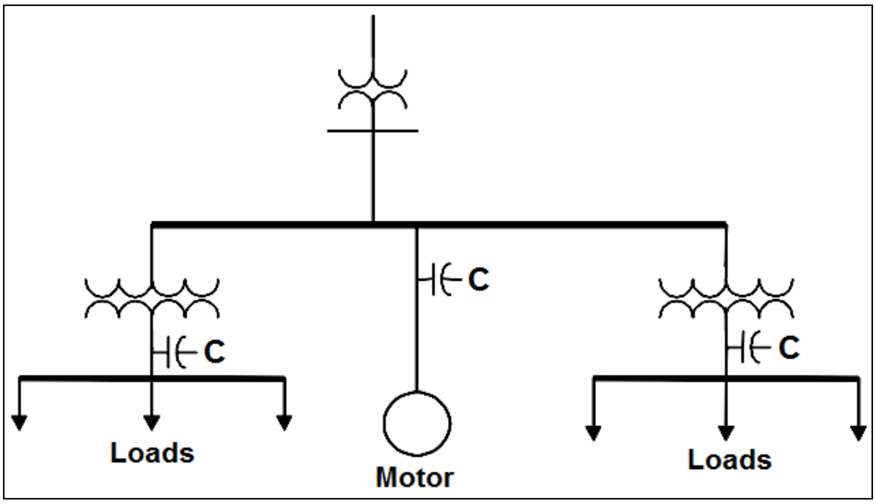
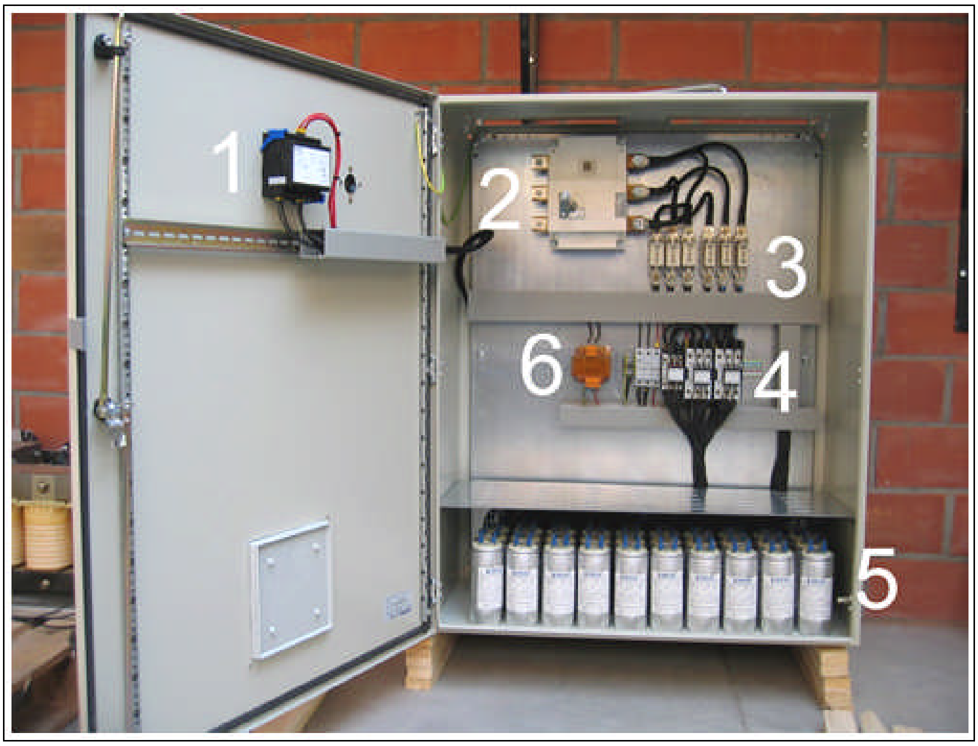


Fig. 2.5-7 Local Capacitor Bank

AUTOMATIC POWER FACTOR CORRECTION UNIT

An automatic power factor correction (Fig. 2.5-8) is used to improve power factor. A power factor correction unit usually consists of a number of capacitors that are switched by means of contactors these contactors are controlled by a regulator that measures power factor in an electrical network. To be able to measure power factor, the regulator uses a current transformer to measure the current in one phase.



1.- Reactive power control relay	2.- Network connection points
3.- Slow-blow fuses	4.- Inrush limiting contactors
5.- Capacitors (single-phase or three-phase units, delta-connection)	6.-Transformer Suitable voltage transformation to suit control power

Fig. 2.5-8 Automatic Power Factor Correction Unit

Depending on the load and power factor of the network, the power factor controller will switch the necessary blocks of capacitors in steps to make sure the power factor stays above a selected value (usually demanded by the energy supplier), say 0.9.

EXAMPLE 2.5-2

A single phase A.C motor (220 V/50 Hz) with a rated power of 2.2 kW. Calculate the current drawn at power factor 0.7 and 0.95

SOLUTION

At power factor 0.7:

$$I = \frac{P}{V\cos\phi} = \frac{2.2X1000}{220X0.7} = 14.28\ A$$

At power factor 0.95:

$$I = \frac{P}{V\cos\phi} = \frac{2.2X1000}{220X0.95} = 10.52\ A$$

EXAMPLE 2.5-3

A fluorescent lamp 220 V has a power factor of 0.5 and draws an operating current of 0.455 A. The power factor is to improve to unity by parallel compensation.
Calculate the current consumption after compensation?

SOLUTION

$P = I \times V \cos \Phi = 0.445 \times 220 \times 0.5 = 50$ W

After compensation

$\cos \Phi = 1$ (unity)

I_2 (current consumption after compensation) = 50/ (220 × 1) = 0.2227 A

SUMMARY

- Power factor is a very important concept in power distribution.
- Power factor is the ratio of true power to apparent power in an AC circuit.
- Power factor likes all ratio measurements, is a unitless quantity.
- In a purely resistive circuit, the power factor is one.
- In a purely inductive and capacitive circuit, the power factor is zero.
- For a load containing only resistance and inductance, the power factor in this case is described as lagging (more than 0 and less than 1).
- For a load containing only resistance and capacitive the power factor in this case is described as leading **(**more than 0 and less than 1).
- Electrical energy supplied at low Power Factor is costly to the supplier as the larger currents require heavier cables and switchgear than that really necessary.
- Capacitor improves the power factor for the system and allows more load to be connected to existing system.
- An automatic power factor correction is used to improve power factor. A power factor correction unit usually consists of a number of capacitors that are switched by means of contactors

FORMULAS

$$\text{Power Factor (P.F)} = \frac{\text{True Power}}{\text{Apparent Power}}$$

$$\text{COS}\,\phi = \frac{P}{S}$$

GLOSSARY

Power triangle	Relate power true, reactive, and apparent in trigonometric form
Power factor	The ratio of true power to apparent power in an AC circuit
Lagging Power Factor	The load current lags voltage
Leading Power Factor	The load current leads voltage
Pure resistive circuit	Current and voltage are in phase, the power factor is zero
Pure inductive circuit	Current lags voltage by 90º, the power factor is zero
Pure capacitive circuit	Current leads voltage by 90º, the power factor is zero
Capacitor units	Series and parallel combinations of capacitor packs or elements put together

REVIEW EXERCISE

1. For the circuit in Fig. 2.5-9, find the true power, reactive power, apparent power and Power Factor.

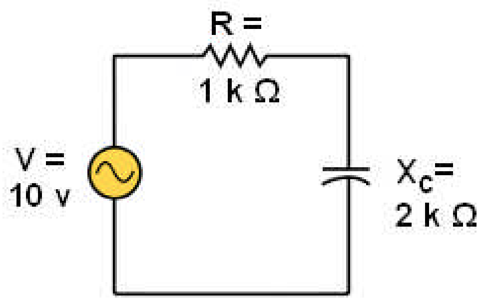


Fig. 2.5-9

2. For the circuit in Fig. 2.5-10. Determine the following:

   a) Impedance of the circuit
   b) Line current
   c) Power factor
   d) Useful power
   e) Reactive power
   f) Apparent power
   g) Phase angle

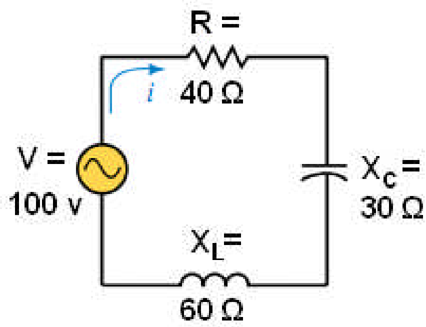


Fig. 2.5-10

Complete by filling in blanks:

3. For a circuit with an apparent power of 3000 VA and a power factor of 0.8, the true power is __________ watts and Power factor is equal to___________.
4. The apparent power in a circuit is 100 VA, and the true power is 80 watts. The true power is __________.
5. In a purely inductive and capacitive circuit, the power factor is_______.
6. For a load containing only resistance and inductance the power factor is described as_______ and equal_______.
7. For a load containing only resistance and capacitive the power factor is described as_______ and equal_______.

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POWER SYSTEM PROTECTION AND CONTROL
STAGE 1-B
Textbook/Workbook 1 Of 2

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